U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-295 052

Process Water Quality Requirements for Iron and Steel Making

IIT Research Inst, Chicago, IL

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, NC

Jan 79

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-79-003	2.
3. RECIPIENT'S ACCESSION NO. PB295052	
4. TITLE AND SUBTITLE Process Water Quality Requirements for Iron and Steel Making	5. REPORT DATE January 1979
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) S. Bhattacharyya	8. PERFORMING ORGANIZATION REPORT NO
9. PERFORMING ORGANIZATION NAME AND ADDRESS IIT Research Institute, 10 West 35th Street, Chicago, Illinois 60616	10. PROGRAM ELEMENT NO. 1BB610
	11. CONTRACT/GRANT NO. 68-02-2617, Task 2-1
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED Task Final; 8/77 - 1/78
	14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is John S. Ruppersberger, MD-62, 919/541-2557.

16. ABSTRACT The report gives results of a study to: develop information on minimum water quality requirements for the different unit processes in iron and steel making; identify data gaps; and recommend research efforts to obtain the required information. The study utilized plant visits, literature, the American Iron and Steel Institute, equipment manufacturers, water chemical suppliers, and consultants. Typical steel plants do not allocate water on the basis of individual processes or recycle water from each process on separate circuits: most do not even record volume or analyze water to individual unit operations. Water is usually distributed to clusters of processing units. Higher quality water is infrequently used for lower quality applications in a cascading manner. In some plants, recycling exceeding 98% is practiced without significant equipment or product quality problems. When equipment problems arise, the present water control technology can usually solve them. Modern equipment is rugged in design and able to accommodate significant water impurities with the help of chemical controls. Insufficient information is available on the effect of water quality on product quality. Water recycling and reuse problems are intimately related to steel plant waste recycling and air pollution problems. One of the researc recommendations is basic data generation on flow and water analysis.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Iron and Steel Industry Industrial Processes Water Quality Water Reclamation	Pollution Control Stationary Sources	13B 11F 13H

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 75
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE A04-A01

EPA Form 2220-1 (9-73)

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/2-79-003
January 1979

Research and Development

PB 295052

EPA

Process Water Quality Requirements for Iron and Steel Making

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

EPA REVIEW NOTICE

This report has been reviewed by the U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policy of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-79-003

January 1979

Process Water Quality Requirements for Iron and Steel Making

by

S. Bhattacharyya

IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Contract No. 68-02-2617
Task No. 2-1
Program Element No. 1BB610

EPA Project Officer: John S. Ruppersberger

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

PREFACE

Water use in the iron and steel industry is basically non-consumptive. More than 90% of the 95,000 to 150,000 liters (25,000 to 40,000 gal) of water required per tonne of steel is returned to large water bodies. But during usage, the water is polluted and the polluting waters contaminate the environment. Significant efforts are now being made to accomplish the following:

- Lessen use of water through recycling and treatment.

- Acquire greater knowledge and understanding of the effect of water purity level on equipment and product quality.

This brief study focuses its attention on the second goal. The study reveals significant gaps in information relating water and product qualities, on the one hand, and water quality and equipment productivity, on the other. Areas of research are identified to close these data gaps.

PREFACE

Water use in the iron and steel industry is basically non-consumptive. More than 90% of the 95,000 to 150,000 liters (25,000 to 40,000 gal) of water required per tonne of steel is returned to large water bodies. But during usage, the water is polluted and the polluting waters contaminate the environment. Significant efforts are now being made to accomplish the following:

- Lessen use of water through recycling and treatment.

- Acquire greater knowledge and understanding of the effect of water purity level on equipment and product quality.

This brief study focuses its attention on the second goal. The study reveals significant gaps in information relating water and product qualities, on the one hand, and water quality and equipment productivity, on the other. Areas of research are identified to close these data gaps.

IIT Research Institute
10 West 35 Street, Chicago, Illinois 60616
312/567-4000

30 January 1979

Editor,
American Institute of Mining
and Metallurgical Engineers
345 East 47th Street
New York, NY 10017

Re: EPA-600/2-79-003:
Table 12 (page 42) and
Table 13 (page 44).

Dear Sir:

The enclosed item(s) is a copy from your publication which we plan to use in a report for US EPA entitled "Process Water Quality Requirements for Iron and Steel Making." This report will eventually be published and sold through US EPA and NTIS.

We will greatly appreciate your permission for use of this material. You may return this letter with your signature and date as an indication of your approval.

Sincerely yours,

S. Bhattacharyya
Manager
Physical Metallurgy

SB/md
Enclosure(s)

You may publish the attached as requested. The credit acknowledgement is acceptable -

Lawrence G Tuthill
Executive Director,
Iron and Steel Society
of AIME.

ia

IIT Research Institute
10 West 35 Street, Chicago, Illinois 60616
312/567-4000

30 January 1979

Editor,
Iron and Steel Engineer
1010 Empire Building
Pittsburgh, PA 15222

Re: EPA-600/2-79-003:
Table 5 (page 26), Fig. 7 (page 27),
Fig. 12 (page 45), Table 14 (page 47),
and App. A (page 59).

Dear Sir:

The enclosed item(s) is a copy from your publication which we plan to use in a report for US EPA entitled "Process Water Quality Requirements for Iron and Steel Making." This report will eventually be published and sold through US EPA and NTIS.

We will greatly appreciate your permission for use of this material. You may return this letter with your signature and date as an indication of your approval.

Sincerely yours,

S. Bhattacharyya
Manager
Physical Metallurgy

SB/md
Enclosure(s)

approved
John A. Gatesch
Editor, Iron and Steel Engineer
Feb. 5, 1979

ASSOCIATION OF IRON
AND STEEL ENGINEERS

1b

KAISER STEEL

KAISER STEEL CORPORATION
STEEL MANUFACTURING DIVISION
P. O. BOX 217 ■ FONTANA, CA 92335

FEBRUARY 22, 1979

MR. S. BHATTACHARYYA
IIT RESEARCH INSTITUTE
10 WEST 35 STREET
CHICAGO, ILLINOIS 60616

Re: EPA-600/2-79-003:
Fig. 6 (page 21).

DEAR MR. BHATTACHARYYA:

MR. RUGGE HAS PASSED ALONG TO ME YOUR LETTER OF JANUARY 30, 1979, FOR KSC APPROVAL OF THE USE OF "FIGURE 6 KAISER STEEL WATER SYSTEMS" WHICH YOU PLAN TO USE IN A REPORT FOR US EPA.

I HAVE SIGNED AND DATED THE ATTACHED SKETCH TO INDICATE APPROVAL FOR THE USE YOU MENTION. IT SHOULD BE NOTED, HOWEVER, THAT THE SKETCH YOU PROPOSE TO USE DOES NOT INCLUDE THE CURRENT MODERNIZATION PROGRAM WATER SYSTEM.

VERY TRULY YOURS,

KAISER STEEL CORPORATION
STEEL MANUFACTURING GROUP

Robert D. Wight

ROBERT D. WIGHT, P.E.
DIVISION SUPERINTENDENT
ENGINEERING AND UTILITIES

CC: H. RUGGE

ENCLOSURE

1c

IIT Research Institute
10 West 35 Street, Chicago, Illinois 60616
312/567-4000

30 January 1979

Editor,
Iron and Steel International
205 E. 42nd Street
New York, NY 10017

Re: EPA-600/2-79-003:
Fig. 5 (page 15), Table 2 (page 16),
and Fig. 13 (page 51).

Dear Sir:

The enclosed item(s) is a copy from your publication which we plan to use in a report for US EPA entitled "Process Water Quality Requirements for Iron and Steel Making." This report will eventually be published and sold through US EPA and NTIS.

We will greatly appreciate your permission for use of this material. You may return this letter with your signature and date as an indication of your approval.

Sincerely yours,

S. Bhattacharyya
Manager
Physical Metallurgy

SB/md
Enclosure(s)

O.K by us
E. A. Hallett
Iron & Steel International
Westbury House, Bury St
Guildford, UK 9.3.79.

1D

PERSONNEL SERVICES

United States Steel Corporation

600 GRANT STREET
PITTSBURGH, PENNSYLVANIA 15230

February 9, 1979

Mr. S. Bhattacharyya
Manager
Physical Metallurgy
IIT Research Institute
10 West 35 Street
Chicago, Illinois 60616

Re: EPA-600/2-79-003:
Fig. 4 (page 14).

Dear Mr. Bhattacharyya:

You have our permission to use the "schematic arrangement of the water treatment system" from our "The Making, Shaping and Treating of Steel" as requested in your January 30, 1979 letter and for the use cited in that letter.

Please make sure the "Copyright 1971 by United States Steel Corporation" accompanies the drawing.

type this at the bottom of the original before reproducing

Sincerely,

Jerry D. Brooks, Manager
Educational Services

JDB:atg

1 E

American Iron and Steel Institute
1000 16th Street, N.W.
Washington, D.C. 20036

February 7, 1979

Re: EPA-600/2-79-003:
Fig. 1 (page 6) and
Fig. 3 (page 12).

Mr. S. Bhattacharyya
Manager, Physical Metallurgy
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Dear Mr. Bhattacharyya:

This is in response to your letter of January 30, 1979, in which you requested permission to use the following items in a report for the USEPA, "Process Water Quality Requirements for Iron and Steel Making."

1. A map, Geograpical distribution of the U. S. iron and steel industry.

2. A flow chart from the A. D. Little report, Steel and the the Environment - A Cost Impact Analysis, entitled "Process unit interrelationships."

Permission is hereby granted.

Very truly yours,

W. C. Benzer

WCB/kms

W. C. Benzer
Metallurgical Engineer

1 F

ABSTRACT

This study was directed to develop information on minimum water quality requirements for the different unit processes in iron and steel making, identify the data gaps, and recommend research efforts needed to obtain the required information. A combination of literature study, plant visits, and discussions with the American Iron and Steel Institute, equipment manufacturers, water chemical suppliers, and consultants was used in this study.

The central finding of this study is that a steel plant neither allocates water on the basis of individual processing units nor recycles water from each processing unit on individual and separate circuits. In fact, the steel plants do not record water flowing in and out of each individual unit, nor do they analyze these waters.

In a steel plant, water is normally used as-received and lime-softened; in a few cases, special treatments are given. Water is distributed to clusters of processing units usually located in close proximity. The distributed water is of a few basic qualities, two to four, and analyses of these basic qualities are made. Higher quality water is infrequently used in a cascading manner for lower quality applications.

In some U.S. as well as foreign steel plants, recycling exceeding 98% of recirculating water is practiced without any significant equipment problem and product quality deterioration. When equipment problems arise, the present water control technology can usually solve the problem. The modern equipment is rugged in design and able to accommodate significant water impurities with the help of chemical controls.

Very little information is available on the effect of water quality on product quality. Water recycling and reuse problems are intimately related to steel plant waste recycling and air pollution problems, and data on these are also limited.

Several research and study recommendations have been made to close the data gaps. One significant recommendation is basic data generation on flow and water analysis at individual consumption points through the installation of flow meters and sampling points.

This report is submitted in partial fulfillment of Contract No. 68-02-2617 by IIT Research Institute under the sponsorship of the U.S. Environmental Protection Agency. The report covers the contract period 31 August 1977 to 5 January 1978.

CONTENTS

Preface ii
Abstract. iii
Figures v
Tables. vi
Acknowledgments vii

1. Introduction 1
2. Conclusions. 2
3. Recommendations. 3
4. United States Iron and Steel Industry. 5
   - Capacity and Distribution 5
   - Producing Units of an Integrated Steel Plant. 8
   - Water System in an Integrated Steel Plant . . 10
5. An Approach to the Study 17
   - Introduction. 17
   - Open Literature 17
   - Iron and Steel Plants 18
   - American Iron & Steel Institute (AISI). . . . 19
   - Equipment Manufacturers 19
6. The Basic Findings and Discussions 20
   - Kaiser Steel Corporation (KSC). 20
   - Armco Steel Corporation (ASC) 25
   - Colorado Fuel & Iron Steel Corporation (CFI). 31
   - Discussions with Groups and Individuals . . . 33
   - Information from Equipment and Water Chemical Suppliers. 41
   - Foreign Steel Plants. 43
   - Recycling of Steel Plant Wastes and Its Relationship to Water Usage 46
   - Some Strip Quality Problems Associated with Water Quality. 50
7. Reuse and Recycling of Water in the Iron and Steel Industry 53

References. 56
Appendices
A. Statistical Highlights of the U.S. Iron and Steel Industry 59

FIGURES

Number		Page
1	Geographical distribution of the U.S. iron and steel industry.	6
2	Total U.S. steel production	7
3	Process unit interrelationships	12
4	Schematic arrangement of the water-treatment system at Fairless Works of United States Steel Corporation	14
5	Water supply and usage at Appleby-Frodingham for the year ending March, 1972	15
6	Kaiser Steel water systems.	21
7	Water supply and distribution to major production areas, Armco Steel Corporation.	27
8	Simplified schematic of the wastewater system, Armco Steel Corporation	28
9	Steel melt shop water system, Armco Steel Corporation	30
10	Mill water distribution, Colorado Fuel & Iron, 1974.	32
11	Simplified material flow diagram, Colorado Fuel & Iron Pueblo plant	36
12	Strip mill cooling water recirculation systems, Hoesch Hüttenwerke, Dortmund, West Germany.	45
13	Particle size distribution for representative samples of ferruginous wastes	51
14	Simplified flow sheet for recycling	55

TABLES

Number		Page
1	The Top 10 Steel Companies of 1976	9
2	Forecast of Water Consumption at Appleby-Frodingham for Year Ending March, 1976	16
3	Kaiser Steel Corporation Average Influent and Effluent Water Analysis at the Water Treatment Plant, 1976	22
4	Analyses of Water of the Four Major Water Streams, Kaiser Steel Corporation	24
5	Mill Water Distribution and Blowdown, Armco Steel Corporation	26
6	Average Analysis of Effluents to Dicks Creek, Armco Steel Corporation, Period 10/1/77 to 10/31/77	27
7	Analysis of Plant Influent (1976), Colorado Fuel & Iron	34
8	Analysis of Plant Effluent for October 1977, Colorado Fuel & Iron	35
9	Water Analysis, National Steel Corporation, Weirton	38
10	Water Analysis, U.S. Steel Fairfield Works, Alabama	39
11	Water Analysis, Youngstown Sheet & Tube, Indiana Harbor	40
12	Mold Deposits in Continuous Steel Casting	42
13	Continuous Steel Casting Problems	44
14	Permissible Impurities in Industrial Wastewater from Rolling Mills, Hoesch Iron & Steel Works, Dortmund, West Germany	47
15	Unit Requirements for Water, USINOR, Dunkirk, France	48
16	Sources and Rates of Production of Iron-Bearing Wastes, British Steel Corporation (BSC), 1975	49

ACKNOWLEDGMENTS

We gratefully acknowledge the cooperation of the following steel plants in supplying data on water flow and quality:

1. Kaiser Steel Corporation, Fontana, California
2. Armco Steel Corporation, Middletown, Ohio
3. Colorado Fuel and Iron Steel Corporation, Pueblo, Colorado

Mr. William Benzer of American Iron and Steel Institute, Washington, D.C., was very helpful in supplying published material and arranging the meeting with the AISI Environmental Committee.

Cooperation of Calgon Corporation and equipment manufacturers, such as Koppers, Loftus, Wilputte, Morgan, and ASEA, were of assistance in this study.

We thank Hydrotechnic Corporation, New York City, for allowing us the use of their updated water flow diagrams of several steel plants and basic water quality data obtained by them on a current EPA program.

Mr. Walter Zabban, Chief Engineer, the Chester Engineers, Pittsburgh, Penn., was a consultant to this study, and discussions with him on any topic related to water treatment and usage in iron and steel industry were very helpful.

Mr. John Ruppersberger, the EPA Project Officer, is to be specially thanked for going out of his way in helping us to remove roadblocks in data gathering.

SECTION 1

INTRODUCTION

During 1967-76, the U.S. steel industry produced a total of 1-1/5 billion tonnes (1-1/3 billion tons)[a] of steel and directly employed 510,000 workers annually. Statistical highlights of the U.S. iron and steel industry are given in Appendix A. Enormous quantities of water were needed at every stage of production. Less than 10% of this water was literally consumed in the process, and the rest of it was returned to the environment. In most instances, the returned water was harmful to some aspect of the environment. This study focuses on one aspect of water usage, namely, on the minimum quality requirements for process water for the various iron and steel making units. Once information on current water quality requirements is identified and quantified, it will be possible to direct research efforts to modify these requirements with lesser water usage as a goal and establish meaningful minimum water quality requirements without compromising product quality or equipment performance and productivity. The complexity of steelmaking technology, the industry's somewhat aging equipment, its highly capital-intensive nature, the magnitude of the risks associated with equipment failure, and the monetary losses associated with off-quality products support the need for establishment of a very thorough data base of minimum water quality requirements that will enhance in-plant water reuse and recycling programs resulting in reduced wastewater discharge.

---

[a] One tonne = 1000 kg = 2205 lb. One ton = 2000 lb.

SECTION 2

CONCLUSIONS

The central finding of this study is that an integrated steel plant does not allocate water on the basis of individual steel processing units or point source categories as defined in EPA effluent guidelines. Water is distributed on the basis of a few basic qualities (as low as two) to clusters of plant units. These basic water qualities have, in most cases, progressive but significant differences. The water qualities are derived not solely on the basis of equipment maintenance/productivity demands or product quality requirements, but on the quality and quantity of the water available and the existing distribution systems. In certain areas, steel plant effluent is the only water source to keep alive a stream and instead of significant recycling most of the water is treated and discharged on a once-through basis.

The equipment used in the steel industry is rugged in nature. Furnaces and machinery can be designed to tolerate acceptable compromises to water quality when properly implemented. However, a lack of knowledge of water chemistry and flow rate entering or leaving an equipment unit makes it virtually impossible to establish meaningful quality adjustments without encountering unacceptable risks of plant breakdown and product quality degradation. This enormous data gap in water quality information at each plant unit needs to be bridged. As a minimum, it will be necessary to install flow meters at the inlets of all major water-consuming points, and to have incorporated in that scheme, sample points for water collection and analysis. These flow and analytical data can then be utilized to determine the tolerance level of equipment and the products they produce. On this basis, further modification can be made for development of effective and economical wastewater treatment technology and total recycle. Outlines of research programs to fulfill this need are given in Section 3.

SECTION 3

RECOMMENDATIONS

Minimum water quality needs for different plant processes/subprocesses are virtually nonexistent, and need to be defined before significant in-plant water reduction programs can be initiated. The information needed to make an intelligent decision regarding minimum water quality for the process has two aspects:

1. Effect on process equipment
2. Effect on product quality and recycling of steel plant metallics.

To study the effect of water quality on process equipment, a two-level research effort is needed. At the plant level, the basic information regarding water quality and flow should be gathered systematically. This should be relatively easy and economically acceptable. At the laboratory level, short- and long-term studies on the effect of water quality on equipment performance must be conducted to obtain an understanding of the minimum water quality that can be sustained by the equipment without loss in normal service life.

A study of the effect of water quality on product quality is more difficult because it will require production of some off-quality products. The scope of the research effort can be limited to finishing units of a steel plant because the effect of water quality on coke production, pig iron, and steel ingot is negligible. The most significant effects of water quality are associated with finished steel products, primarily the coated and cold-rolled flat products. In steel finishing, there is also a significant paucity of knowledge, and studies are required independently as well as with collaboration of the steel industry. A few research suggestions are given below:

1. Establish correlation between non-adherence of paints on auto body panels and their accelerated corrosion with localized surface contamination resulting from residual oil and/or iron salts left on the sheets after cleaning.
2. Determine the relationship between water-oil emulsion quality and oil-burn phenomena on cold-rolled steel sheets.

3. Develop oily sludge treatment to make them suitable for recycling without causing air pollution and equipment operation problems.

4. Determine if the use of dry film graphite lubricant is an acceptable alternative to oil and grease.

5. Develop heavy metal removal technology particularly with emphasis on total recycling of vacuum degassing water.

6. Advance technology for chromium recovery from plating liquor and sludge.

7. Determine degree of built-in overdesign in existing equipment, to enable efficient operation with lower water quality than currently used.

8. Techno-economic study to replace existing cooling tower system for cooling non-contact cooling water of blast furnace stave and tuyere cooling, and BOF hood and lance cooling with completely demineralized water in a totally enclosed circuit with air-cooled heat exchanging facility.

9. Use simulation techniques and accelerated tests to determine the effect of water quality on steel and iron making equipment.

10. Develop a computer model incorporating material and heat flow in making one ton of finished steel to predict minimum water requirement per ton steel produced using combinations of different water qualities and partial or total recycling.

SECTION 4

UNITED STATES IRON AND STEEL INDUSTRY

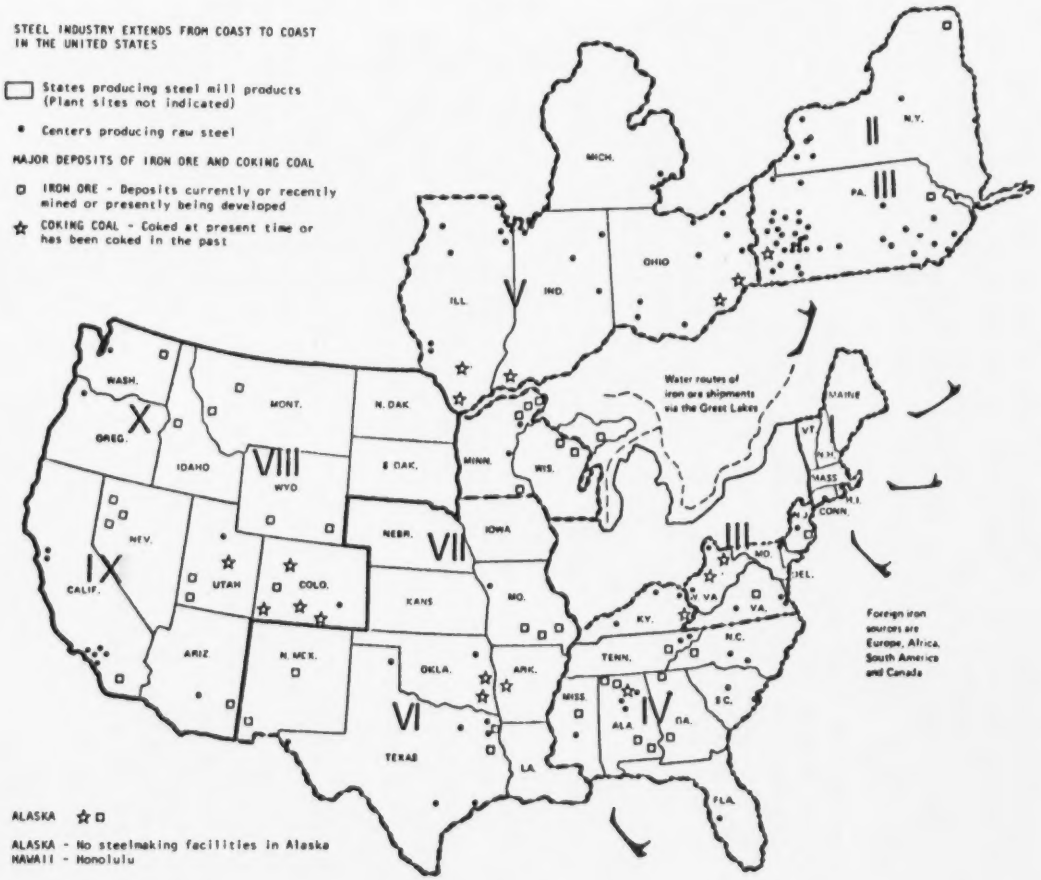
CAPACITY AND DISTRIBUTION

From less than 10.9 10^6 tonnes (12 million tons) in 1900, U.S. raw steel production reached a high of 137 x 10^6 tonnes (151 million tons) in 1973. The production of 116 x 10^6 tonnes (128 million tons) in 1976 increased to about 119 x 10^6 tonnes (131 million tons) in 1977. To provide a perspective, in 1976 the steel productions of Japan, European Economic Community (EEC), and USSR were 107, 134, and 147 million tonnes, respectively,[1] out of a total world steel production of 683 x 10^6 tonnes (753 million tons).

While the above tonnage figures between the countries are all comparable, there are significant differences in the producing units. Japan has virtually rebuilt its capacity during the last 25 years and has the most modern and productive equipment. Much of the EEC and USSR plants are more modern than the USA's. EEC plants do not have to serve far-flung communities as they are very tightly clustered in the heart of Western Europe. Until the late 60's, USSR plants had similar distribution, two major areas, one in the Ukraine and the other at the Urals, centered in Magnitogorsk, about 2400 km (1500 miles) apart.

The majority, 65 to 70%, of the U.S. steel industry is situated in a six-state region bordering the Great Lakes, as shown in Fig. 1.[2] They obtain their need of billions of liters of daily water requirements from the Great Lakes and the large river complexes in these states. Because of ample supply of clean water, the industry had very little problem in meeting the water needs of steel production.

The present installed U.S. steel capacity is about 145 x 10^6 tonnes (160 million tons). Various growth projections have been made, and one such estimate is shown in Fig. 2.[3] According to Fig. 2, by 1980 an installed capacity of about 168 x 10^6 tonnes (185 million tons) will be needed to produce 151 x 10^6 tonnes (167 million tons) of raw steel if all the additional million tons of steel demand are not to be lost to imports. In 1977, a record import of 17 million tonnes (24 million tons raw steel) took place.



LOCALITIES WHERE RAW STEEL IS MADE:

ALABAMA
- Birmingham
- Fairfield
- Gadsden

ARIZONA
- Tempe

CALIFORNIA
- Emeryville
- Etiwanda
- Fontana
- Long Beach
- Los Angeles
- Torrance
- Union City

COLORADO
- Pueblo

CONNECTICUT
- Bridgeport

DELAWARE
- Claymont

FLORIDA
- Tampa

GEORGIA
- Atlanta

HAWAII
- Honolulu

ILLINOIS
- Alton
- Chicago
- Chicago Heights
- Granite City
- Kankakee
- Lemont
- Morton Grove
- Peoria
- South Chicago
- Sterling

INDIANA
- East Chicago
- Fort Wayne
- Gary
- Kokomo
- New Castle
- West Chester

KENTUCKY
- Ashland
- Newport
- Owensboro

MARYLAND
- Baltimore
- Sparrows Point

MICHIGAN
- Dearborn
- Ecorse
- Ferndale
- Trenton
- Warren

MINNESOTA
- Duluth
- St. Paul

MISSISSIPPI
- Flowood

MISSOURI
- Kansas City

NEW JERSEY
- Roebling

NEW YORK
- Buffalo
- Dunkirk
- Lackawanna
- Lockport
- New Hartford
- Syracuse
- Watervliet

NORTH CAROLINA
- Croft
- Monroe

OHIO
- Campbell
- Canton
- Cincinnati
- Cleveland
- Lorain
- Mansfield
- Middletown
- Portsmouth
- Steubenville
- Warren
- Youngstown

OKLAHOMA
- Sand Springs

OREGON
- Portland

PENNSYLVANIA
- Aliquippa
- Beaver Falls
- Bethlehem
- Brackenridge
- Braddock
- Braeburn
- Bridgeville
- Burnham
- Butler
- Carnegie
- Coatesville
- Duquesne
- Erie
- Fairless Hills
- Farrell
- Harrisburg
- Houston
- Irvine
- Ivy Rock
- Johnstown
- Latrobe
- McKeesport
- Midland
- Milton
- Monaca
- Monessen
- Munhall
- New Castle
- Oakmont
- Philadelphia
- Phoenixville
- Pittsburgh
- Reading
- Steelton
- Titusville
- Washington
- West Homestead

RHODE ISLAND
- Philipsdale

SOUTH CAROLINA
- Cayce
- Georgetown

TENNESSEE
- Harriman
- Knoxville

TEXAS
- Fort Worth
- Houston
- Lone Star
- Longview
- Pampa
- Seguin
- Winton

UTAH
- Geneva

VIRGINIA
- Chesapeake
- Newport News
- Roanoke

WASHINGTON
- Seattle

WEST VIRGINIA
- Huntington
- Weirton

Source: American Iron and Steel Institute, "Geography of Iron and Steel in the United States"

Figure 1. Geographical distribution of the U.S. iron and steel industry.(2)

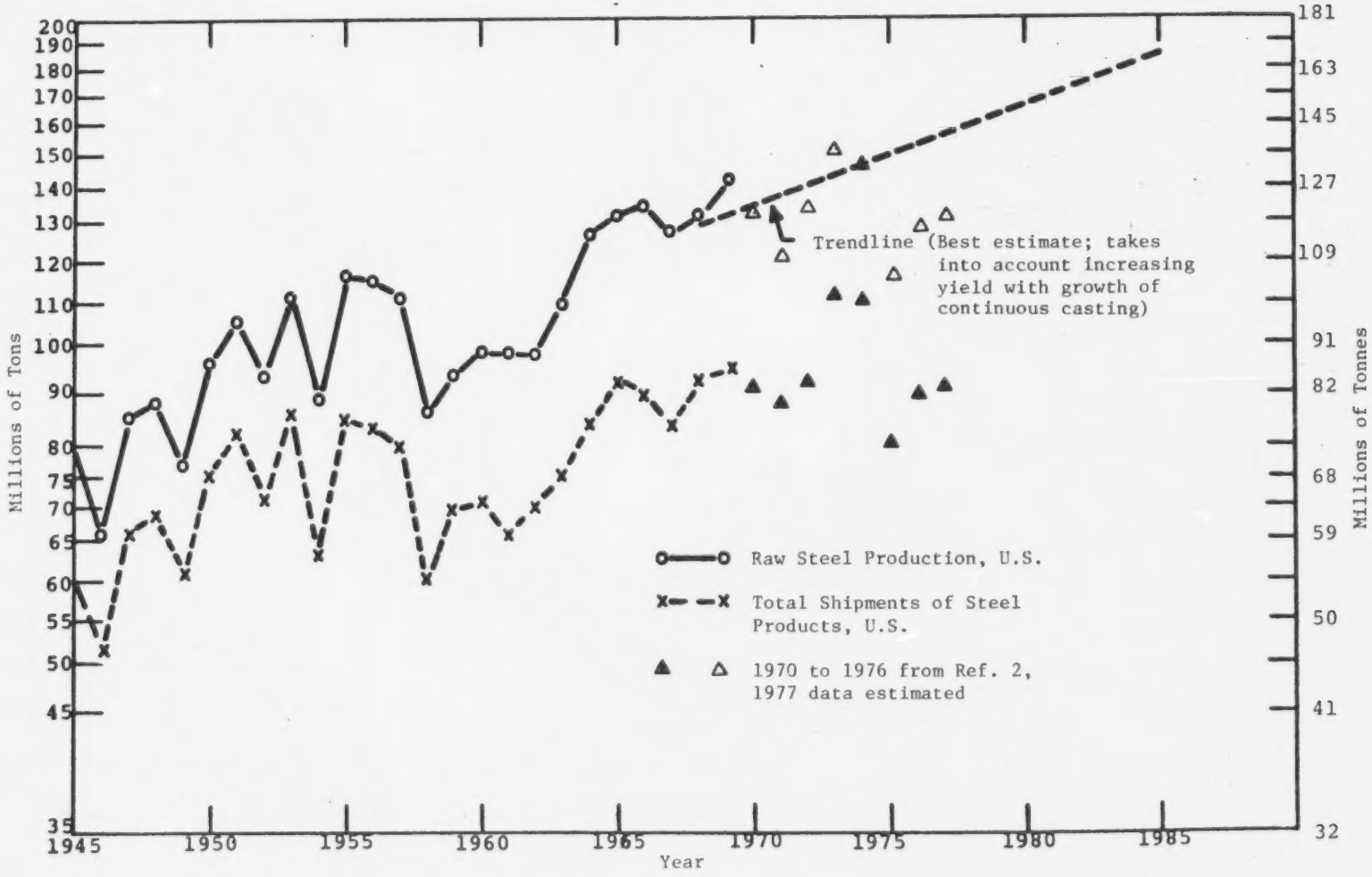


Figure 2. Total U.S. steel production.[3]

Using a quantitative economic analytical technique, Mo and Wang[4] projected a 2.9% average annual growth rate to 140 million tonnes (154 million tons) finished steel, equivalent to about 181 million tonnes (200 million tons) of raw steel. Even assuming an import contribution of 17 million tonnes (19 million tons) of finished steel (raw steel 24 million tonnes, 26 million tons), a domestic raw steel production of 158 million tonnes (174 million tons) will require 172 million tonnes (190 million tons) of raw steel capacity.

Thus, it appears that a minimum of 163 million tonnes (180 million tons) of raw steel capacity will be required in the next 3 to 5 years. In other words, almost 4 million tonnes of raw steel capacity must be added every year for the next few years, apart from modifications, modernization, and environmental expenses. On the other hand, any new and modernized capacities designed with environmental considerations in mind will appreciably reduce the problems associated with water pollution.

The major steel producers are all integrated mills, i.e., they have their own coke plants, blast furnaces, steel melt shops, and mills within a single boundary and authority. Table 1 lists the top ten steel companies and their production, revenue, and employment costs.[5]

PRODUCING UNITS OF AN INTEGRATED PLANT

Pig iron (also called hot metal) is produced in tall reactors (blast furnaces) from iron-bearing raw materials such as ores, pellets, sinter and scrap, fluxed with limestone. Coke is required to provide energy for smelting and is the reducing medium for iron production. Modern blast furnaces are very large units, as large as 10,000 tonnes/day. A 4000 tonne/day blast furnace may require as much as 200 million liters (50 million gallons) of water daily. Large piles of raw materials are usually stored in the open with complete environmental exposure.

Coke is made in closed rectangular ovens by destructive distillation of raw crushed coal. In addition to coke, coke ovens produce a valuable gas and many chemicals which are normally recovered. These are ammonia, tars, light oils, phenol, and benzene. In addition, fine particles of coal and coke are generated in profusion. Coal stored in large piles is also exposed to weather.

An agglomerated product, called sinter, is often a substantial portion of iron-bearing charge in a blast furnace. This product is made from natural and crushed fines of iron ore, coke, limestone, mill scale, and flue dusts, much of which will otherwise be discarded as waste. The sinter plant consists of a long traveling grate furnace on which the mixture is burned under conditions to obtain a desired product.

TABLE 1. THE TOP 10 STEEL COMPANIES OF 1976[5]

Company	Raw Steel Production, millions of tonnes[a]	Sales Revenues, billion $	Employment Costs		Net Income, million $	Long-Term Debt, billion $
			billion $	% of sales		
U.S. Steel Corp.	25.7 (28.3)	8.725	3.578	41.0	410.3	1.960
Bethlehem Steel Corp.	17.1 (18.9)	5.305	2.314	44.1	168.0	1.023
Armco Steel Corp.	6.9 (7.6)	3.165	0.974	30.9	123.7	0.667
National Steel Corp.	9.8 (10.8)	2.841	0.885	31.2	85.7	0.744
Republic Steel Corp.	8.7 (9.6)	2.546	0.911	35.8	65.9	0.372
Inland Steel Corp.	7.2 (7.9)	2.401	0.738	30.9	104.0	0.480
Jones & Laughlin Steel Corp.	6.3 (7.0)	2.052	0.735	35.8	44.4	0.349
Lykes-Youngstown Corp.	4.6 (5.1)	1.643	0.592	36.5	19.0	0.673
Wheeling-Pittsburgh Steel Corp.	3.5 (3.9)	0.936	0.375	40.1	3.2	0.183
Allegheny Ludlum Steel Corp.	0.7 (0.8)	0.902	0.304	33.6	30.7	0.177

[a] Figures in parentheses are in million tons

The molten pig iron contains significant amounts of impurities, and to produce steel these are oxidized and fluxed away in basic oxygen converters (BOF), open hearths (OH), and electric arc furnaces (EF). Until 1968, OH was the major steelmaking process requiring less of pig iron and more of scrap. In 1976, over 60% of raw steel was produced by BOF, projected to increase to 80% by 1980. BOF requires 70% of its charge to be pig iron. The impact of this technological turnabout is reflected in installation of large blast furnaces (Bethlehem, 7600 tonnes/day and Inland, 6300-9900 tonnes/day) and coke ovens to feed them, both requiring very large quantities of cooling water.

Simultaneously, with the advant of BOF, continuous casting of molten steel has made rapid progress. over batch casting of large ingots. While traditional ingot casting required very little cooling water, continuous casting requires a very high volume of water, often of different purity levels, one of which requires special treatment. The other water stream gets highly contaminated with scale.

Vacuum degassing of molten steel is also a significant developing technology. The nature of the process is such that some of the metallic elements including heavy metals are pulled out and enter the waste stream after gas cleaning.

After casting, the large ingots or continuous cast slabs and billets are heated and shaped by passing through large cylindrical or shaped rollers. The heating in large furnaces and soaking pits requires a significant amount of water for cooling. In the rolling process a very large volume of water is needed for cooling the rollers, bearings, and the products, as well as for cleaning the thick scales from the product by high-pressure water jets before the start of rolling. Moreover, oil is used in oil-water emulsions for cold rolling. Thus, a complex water stream is generated from the shaping operation.

In addition to shaping, many of the flat products are supplied with coatings of zinc, tin, lead-tin alloy, chromium, and polymers. To prepare for coating, the steel materials are cleaned of surface scales by acid pickling. Thus the coating operations generate a complex wastewater stream containing acids and their salts plus metal and organic coating materials--and this stream is one of the most difficult to handle.

An overall flow pattern of the steelmaking process is shown in Fig. 3.[2]

WATER SYSTEM IN AN INTEGRATED STEEL PLANT

While Fig. 3 shows the complex pattern of material flow in a steel plant, the water system to accomplish efficient operation is far more complex, as shown in Fig. 4.[6] In Fig. 4, the finishing units of sheet and tin mill and tube plant form the most complex water system consisting of acids, oils, and scales. Eventually, sludge is removed, pickle liquor is dumped, and

flocculator oil skimmings are burned. The hot strip mills and the tube mill form another complex while the coke oven, blast furnace, and open hearth form a third complex. The fourth complex is essentially the power plant.

The diversity of water treatment, its routing and usage, may be even more clearly seen in the schematic water use pattern shown in Fig. 5 for Appleby-Frodingham Steel Co. of the U.K.[7] The circulating water amounts to 150,000 liters/tonne of steel (36,000 gal/ton)[a] of which 3100 liters/tonne (750 gal/ton) are consumed. Of the 3100 liters/tonne consumption, about 90% is lost in evaporation and the remainder is discharged to water bodies. About 40% of the circulating water is used under lime-softened condition, another 40% as received, and the remaining 20% with special treatments.

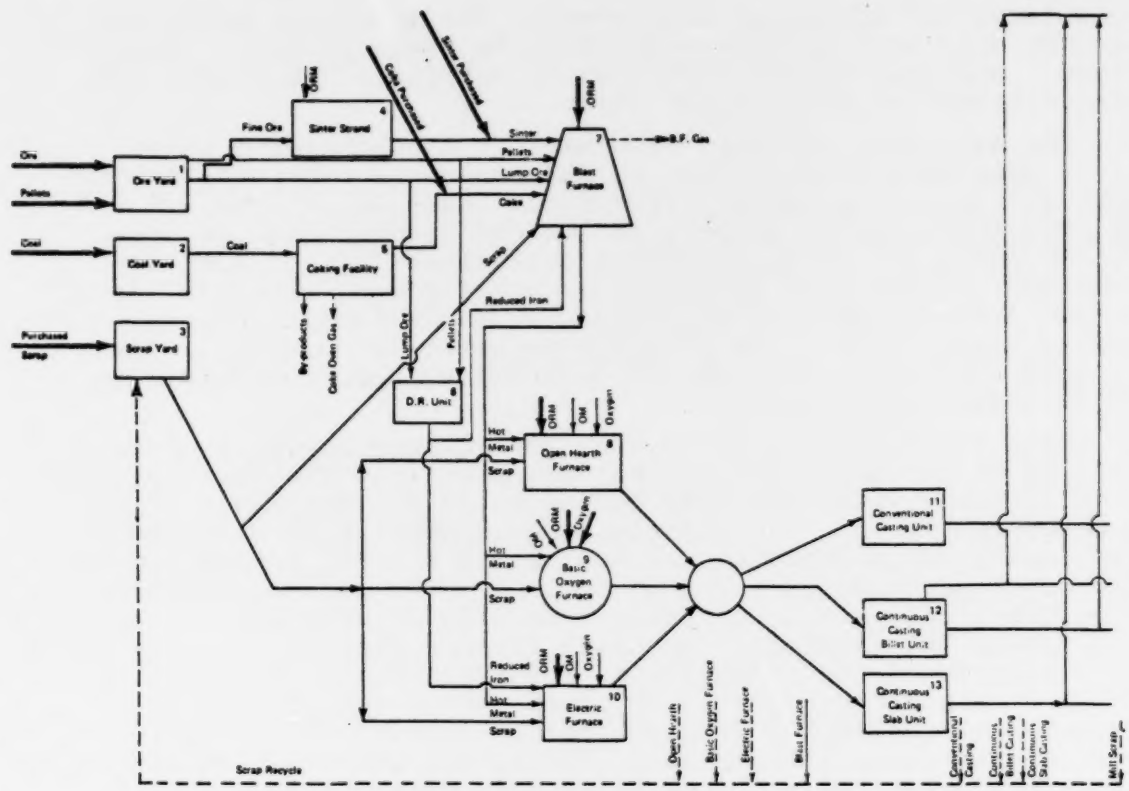
With recirculation and usage, contaminant levels tend to build up in the water streams but do not change the basic nature of the treated water which is fed to the different plant units, as shown in Fig. 5. The anticipated consumption of water per plant units for a production level of 4.5 million tonnes (5 million tons) per year is given in Table 2. The consumption rate of 24,000 liters/min is equivalent to 2900 liters/tonne of steel, i.e., about 700 gal/ton. The blast furnace complex accounts for a quarter of the consumption, followed by 14% in coke ovens and 9% at the sinter plant. In other words, all activities directly related to pig iron production account for 51% of the total consumption. It has been pointed out earlier that with the technological switch from OH to BOF, more pig iron will be needed to produce a ton of steel and thus will increase water consumption. This increase can be offset by judicious recycling and design of water treatment units.

At the ARBED Esch-Belval works in Luxemburg[8] with a raw steel production capacity of 1.4 million tonnes/year, the specific water consumption is betwen 1200 and 1700 liters/tonne of steel, i.e., between 290 and 400 gal/ton. All the water recirculation systems of the works are of closed design laid on a cascade basis.

At the USINOR's Dunkirk plant[9] in France, at 8 million tonne/year production stage, a water consumption of only 1800 liters/tonne is planned, i.e., 430 gal/ton. At both USINOR and ARBED, great attention is given to establish a rain-water network which is used for cooling pig iron, granulating the blast furnace slag, spraying the slag and cinder pits. etc.

---

[a] 1 gallon = 3.785 liters



LEGEND:

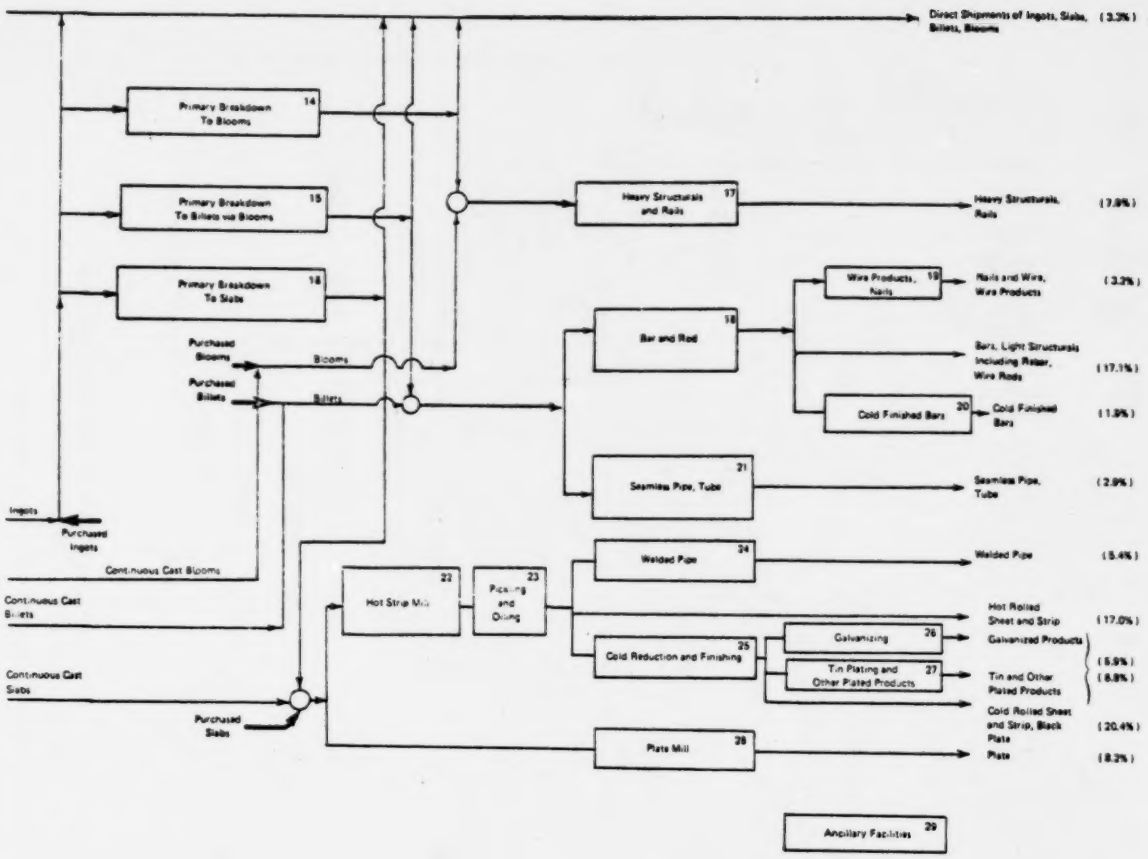
——— In-plant flows

– – – Scrap recycle

▬▬ Flows from outside

○ Flow streams joined to obtain common cost to following process

Figure 3. Process unit interrelationships[2]


Direct Shipments of Ingots, Slabs, Billets, Blooms (3.3%)
Primary Breakdown To Blooms 14
Primary Breakdown To Billets via Blooms 15
Primary Breakdown To Slabs 16
Heavy Structurals and Rails 17
Heavy Structurals, Rails (7.8%)
Wire Products, Nails 19
Nails and Wire, Wire Products (3.3%)
Bar and Rod 18
Bars, Light Structurals including Rebar, Wire Rods (17.1%)
Cold Finished Bars 20
Cold Finished Bars (1.8%)
Seamless Pipe, Tube 21
Seamless Pipe, Tube (2.9%)
Welded Pipe 24
Welded Pipe (5.4%)
Purchased Blooms
Blooms
Purchased Billets
Billets
Ingots
Purchased Ingots
Continuous Cast Blooms
Continuous Cast Billets
Continuous Cast Slabs
Purchased Slabs
Hot Strip Mill 22
Pickling and Oiling 23
Cold Reduction and Finishing 25
Galvanizing 26
Tin Plating and Other Plated Products 27
Hot Rolled Sheet and Strip (17.0%)
Galvanized Products (5.9%)
Tin and Other Plated Products (0.8%)
Cold Rolled Sheet and Strip, Black Plate (20.4%)
Plate Mill 28
Plate (8.2%)
Ancillary Facilities 29

NOTES:

1. ORM refers to other raw materials and includes items such as fluxes.
2. OM refers to other metallics and includes items such as ferroalloy additions.
3. Each box, though representing a process unit, may include several steps, for example:
   Coking Facility: Includes coke ovens and by-products facility.
   Primary Mills: Includes billet conditioning and slab preparation.
   Plate and Rod Mills: Includes finishing.
   Pipe Mills: Includes galvanizing and finishing.
   Tin Mills: Includes coating and finishing.
   Wire Products: Includes annealing, galvanizing, straightening, cutting, and finishing.
4. At the right-hand end of the figure are the different categories of carbon steel products shipped by the U.S. iron and steel industry. The figures in parentheses show the contribution of that category of shipment as a percentage of the total in 1972.
5. Process units 11, 12, 13 would include vacuum degassing operations when found in a plant.

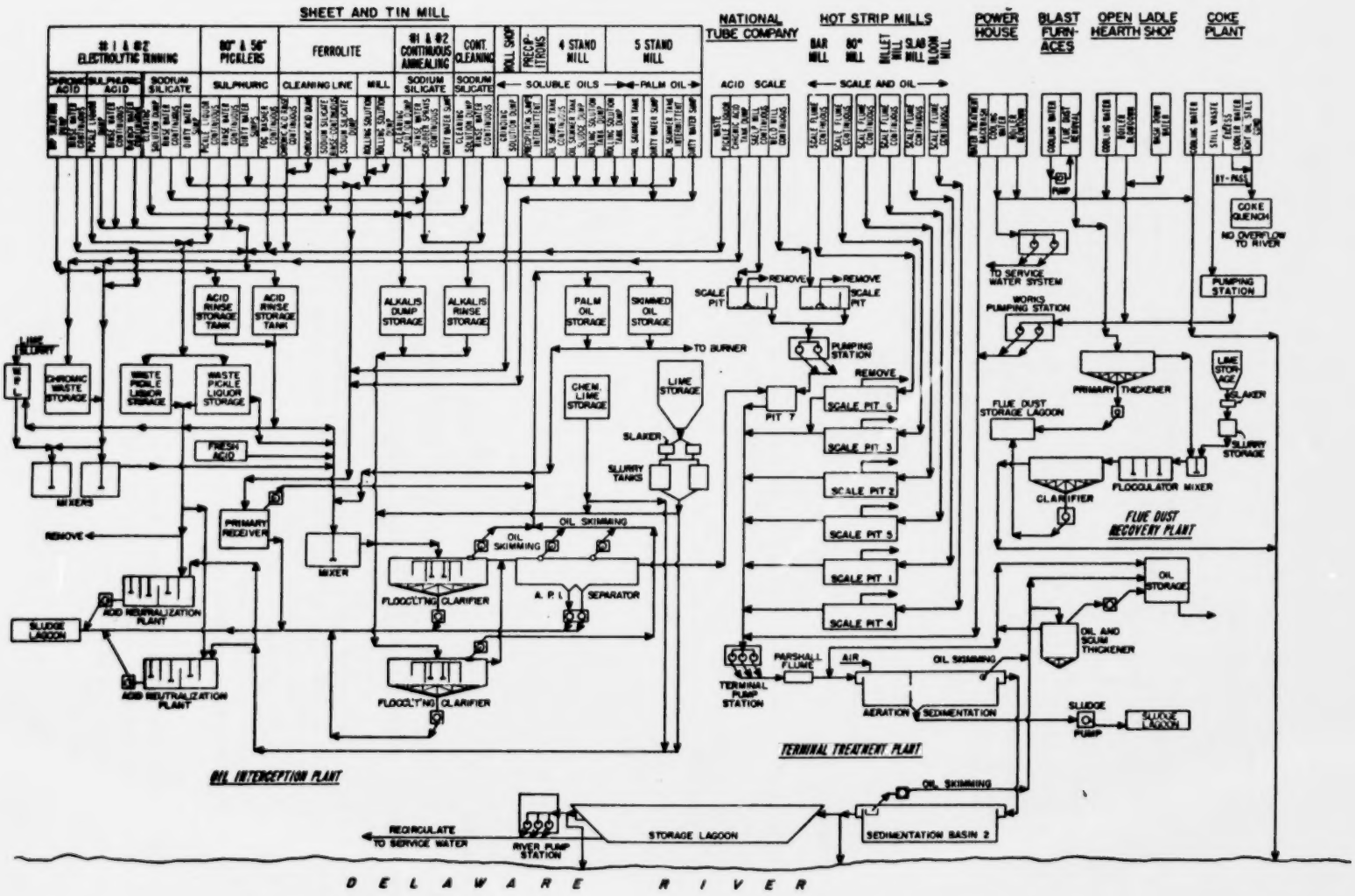


Figure 4. Schematic arrangement of the water-treatment system at Fairless Works of United States Steel Corporation.(6)
(Copyright 1971 by United States Steel Corporation)

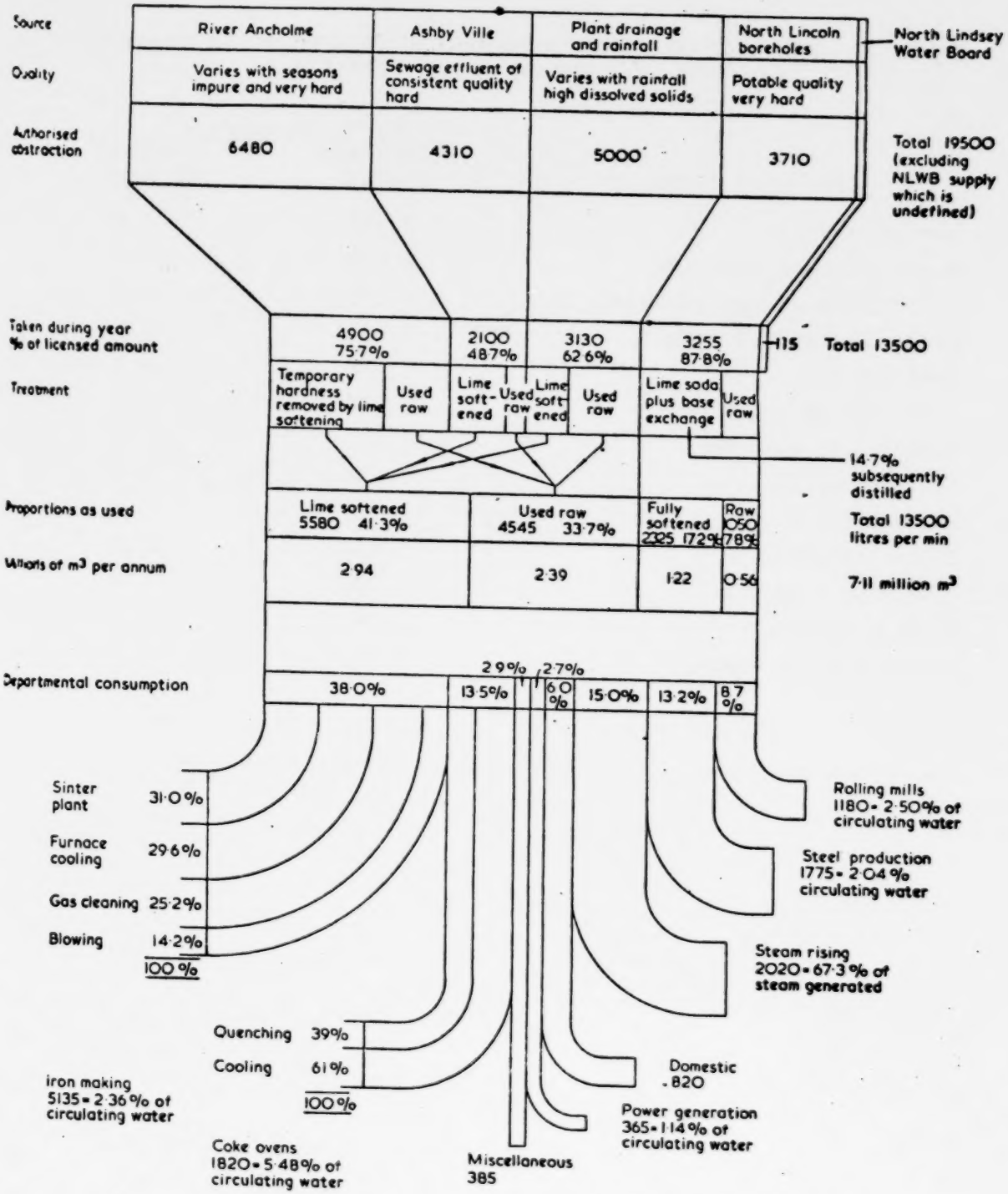


Figure 5. Water supply and usage at Appleby-Frodingham for the year ending March, 1972.(7)

TABLE 2. FORECAST OF WATER CONSUMPTION AT APPLEBY-FRODINGHAM FOR YEAR ENDING MARCH, 1976[7]

Consuming Plant	Water Consumption liters/min avg	Water Consumption percent of total
Sinter plants	2,225	9.3
Blast furnace cooling	2,450	10.2
Blast furnace gas cleaning	1,545	6.4
Blast furnace blowing	2,590	10.8
Coke ovens	3,540	14.7
Steelmaking - BOF	1,500	6.2
Continuous casting	1,000	4.2
Rolling mills	1,590	6.6
Electrical power generation	1.225	5.1
Steam raising	2,880	12.0
Domestic purposes	1,000	4.2
Slag quenching	1,045	4.4
Miscellaneous users	1,410	5.9
Total	24,000	100.0

SECTION 5

AN APPROACH TO THE STUDY

INTRODUCTION

The objective of this study was to develop data on minimum water quality requirements for different unit processes of the iron and steel industry. One would logically assume that much of this information is available in the open literature, a careful analysis of which should identify the data sought for and reveal any gaps to be filled. Thus, the four basic questions posed in the work assignment could be answered adequately.

It was also expected that a wealth of information must be available with the water management divisions in the steel industry which could be obtained by correspondence with several steel plants followed by plant visits and discussions, where necessary. In addition, the iron and steel industry trade association, the American Iron and Steel Institute (AISI), must be collecting this information and would have a generous data bank to share with IITRI for this study.

Furthermore, because equipment is designed to meet certain performance criteria relating to heat transfer, flow rate, pressure, temperature, scaling, fouling, and erosion, the equipment manufacturers must have a set of guidelines regarding water qualities such as pH, temperature, total dissolved solids (TDS), total suspended solids (TSS), alkalinity and similar parameters to enable them to design the equipment system. Thus, the equipment manufacturers were considered another information source for this study.

Unfortunately, on each of the above three counts the outcome has been less than satisfactory, if not disappointing.

OPEN LITERATURE

Within the time frame of this study, a thorough manual and computer-aided search was made for water quality information in the steel industry, and the result has been disappointing. The computer search yielded no significant specific information. A manual search of relevant sources resulted in some data collection, mostly non-specific in nature. The reason is that, till

the mid 1960's, water quality, whether going into a processing unit or being thrown out to a water body, was not considered to be significant in the steel industry because of ample supply, low cost, and lack of knowledge and concern about environmental impact of polluted water. Thus, hardly any data on water quality levels at individual plant units were kept, let alone published.

In view of heightened environmental awareness and EPA effluent guideline regulations, considerable data are now being collected on discharges. But since there are no EPA requirements for water quality documentation at equipment inlet and recycling streams, there is still very little relevant information available in the literature. A strong case can be made for such documentation. Most of the data in the literature pertain to flow rate, pH, TSS, TDS, and alkalinity on water streams as a whole for the entire plant or for a large combination of units. No specific data are available in the open literature on inlets and outlets of 30 specific plant units, defined as point source categories in the effluent guidelines.[10-12] In each of these 30 units there are dozens of separate water streams and consumption points, and obviously no information is available at these subunits or locations.

IRON AND STEEL PLANTS

The majority of the steel plants are clustered around the Great Lakes (Fig. 1). The assurance of ample clean water was a major consideration for their location. An equally important reason was the availability of these water bodies as recipients of the polluted discharge from the steel plants. Thus, in most plants, the basic treatment was nil or minimal--only elimination of excess suspended solids. The water was used as received or merely lime-softened, if required.

A few plants are located in water-scarce regions; a prime example is Kaiser Steel Corporation (KSC) at Fontana near Los Angeles. Some plants are in arid/semi-arid regions; an example is Colorado Fuel and Iron (CFI) at Pueblo. KSC was constructed in the 40's and specifically designed for extensive water recycling. Thus, they kept possibly the best set of data on water quality.

In the Ohio valley, river pollution from steel mill wastes became a source of major community concern long before the national concern expressed in the creation of EPA. Armco Steel Corporation (ASC), Middletown, Ohio, initiated a set of measures for extensive water recycling, and their data collection on effluent is significant.

AMERICAN IRON AND STEEL INSTITUTE (AISI)

AISI, unfortunately, has no centralized data bank on water quality requirements in the steel industry, and was unable to help IITRI in providing these data. They readily gave IITRI a collection of their published studies and requested IITRI to contact individual steel plants to obtain the necessary data. A meeting was held with AISI Environmental Committee at Pittsburgh.

EQUIPMENT MANUFACTURERS

Several invidual steel plant equipment suppliers were contacted for design information on water quality for their equipment. The general response was that they did not have any specific requirement unless it was a power plant or some such special unit. They design their equipment based on steel plants' water supply information, which is very general in nature. Thus, the source of equipment supplier did not result in significant data generation.

Most recently some information regarding water quality on product quality was presented in a society meeting and also appeared in a weekly metalworking publication. These data are, possibly, the most specific to date on this subject.

Our approach to data collection and information development covered all possible avenues. Because significant and critical data on minimum water quality requirements for process water and product quality are not there, it will be necessary to undertake research studies to obtain more specific data and this is recommended later.

SECTION 6

THE BASIC FINDINGS AND DISCUSSIONS

The information reported in this section was obtained basically from plant visits, open literature, and discussions with individuals.

Three steel plants were visited:

Armco Steel Corporation (ASC), Middletown, Ohio

Colorado Fuel and Iron Steel Corporation (CFI), Pueblo, Colorado

Kaiser Steel Corporation (KSC), Fontana, California.

KAISER STEEL CORPORATION

KSC recycles about 98% of its water. Its net consumption is 4600 l/tonne (1100 gal/ton).[13] Of this only about 960 l/ton (230 gal/ton) is finally discharged to a municipal wastewater plant, which treats it for discharge to the ocean. This exceptionally low discharge of 960 l/tonne is much better than the best data from steel plants such as ARBED, Luxemburg; Dunkirk, France; and Appleby-Frodingham, U.K., mentioned earlier. However, the total requirement will increase to about 3400 l/min (9000 gpm), and discharge between 5700 and 7200 l/min (1500 and 1900 gpm) with the addition of new BOF and continuous casting units now under construction.

Much has already been written about KSC's cascade system of water usage. In this system water of the highest quality once used is reused in the next system requiring lower quality and so on. Four such systems are used along with some special water systems, as shown in Fig. 6.[14] The system was planned this way from the start because of the arid nature of the region.

The analyses of influent and effluent streams at the water treatment plant are given in Table 3. Though flow charts show that the water stream from the domestic reservoir flows directly into the industrial reservoir, a difference in the analyses between these two qualities exists. It is noted that in the solid contents and hardness level, the industrial water is higher. This is so because the plant is not on a level ground

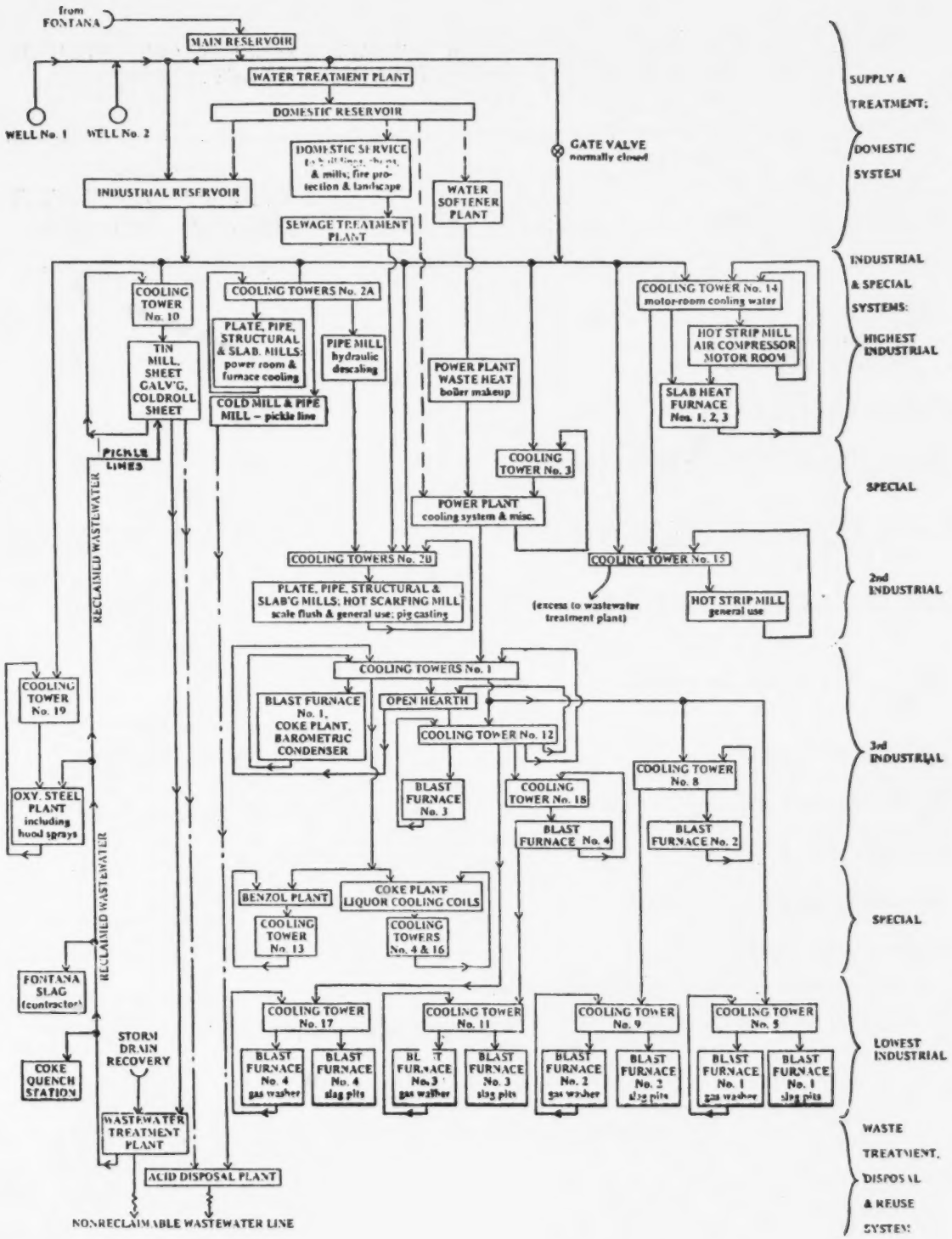

from FONTANA
MAIN RESERVOIR
WATER TREATMENT PLANT
DOMESTIC RESERVOIR
WELL No. 1
WELL No. 2
DOMESTIC SERVICE & mills; fire protection & landscape
GATE VALVE normally closed
INDUSTRIAL RESERVOIR
WATER SOFTENER PLANT
SEWAGE TREATMENT PLANT
SUPPLY & TREATMENT; DOMESTIC SYSTEM
INDUSTRIAL & SPECIAL SYSTEMS:
COOLING TOWER No. 10
COOLING TOWERS No. 2A
COOLING TOWER No. 14 motor-room cooling water
HOT STRIP MILL AIR COMPRESSOR MOTOR ROOM
PLATE, PIPE, STRUCTURAL & SLAB. MILLS: power room & furnace cooling
PIPE MILL hydraulic descaling
TIN MILL, SHEET GALV'G, COLDROLL SHEET
COLD MILL & PIPE MILL – pickle line
POWER PLANT WASTE HEAT boiler makeup
SLAB HEAT FURNACE Nos. 1, 2, 3
HIGHEST INDUSTRIAL
PICKLE LINES
COOLING TOWER No. 3
POWER PLANT cooling system & misc.
SPECIAL
RECLAIMED WASTEWATER
COOLING TOWERS No. 2B
COOLING TOWER No. 15
PLATE, PIPE, STRUCTURAL & SLAB'G MILLS; HOT SCARFING MILL scale flush & general use; pig casting
(excess to wastewater treatment plant)
HOT STRIP MILL general use
2nd INDUSTRIAL
COOLING TOWERS No. 1
COOLING TOWER No. 19
BLAST FURNACE No. 1, COKE PLANT, BAROMETRIC CONDENSER
OPEN HEARTH
COOLING TOWER No. 12
COOLING TOWER No. 8
BLAST FURNACE No. 3
COOLING TOWER No. 18
OXY. STEEL PLANT including hood sprays
BLAST FURNACE No. 4
BLAST FURNACE No. 2
3rd INDUSTRIAL
BENZOL PLANT
COKE PLANT LIQUOR COOLING COILS
COOLING TOWER No. 13
COOLING TOWERS No. 4 & 16
SPECIAL
FONTANA SLAG (contractor)
COOLING TOWER No. 17
COOLING TOWER No. 11
COOLING TOWER No. 9
COOLING TOWER No. 5
BLAST FURNACE No. 4 gas washer
BLAST FURNACE No. 4 slag pits
BLAST FURNACE No. 3 gas washer
BLAST FURNACE No. 3 slag pits
BLAST FURNACE No. 2 gas washer
BLAST FURNACE No. 2 slag pits
BLAST FURNACE No. 1 gas washer
BLAST FURNACE No. 1 slag pits
LOWEST INDUSTRIAL
STORM DRAIN RECOVERY
COKE QUENCH STATION
WASTEWATER TREATMENT PLANT
ACID DISPOSAL PLANT
WASTE TREATMENT, DISPOSAL & REUSE SYSTEMS
NONRECLAIMABLE WASTEWATER LINE

Figure 6. Kaiser Steel water systems.[14]

TABLE 3. KAISER STEEL CORPORATION AVERAGE INFLUENT AND EFFLUENT WATER ANALYSIS AT THE WATER TREATMENT PLANT, 1976[14]

Item	Influent	Effluent	
		Domestic Reservoir	Industrial Reservoir
pH	7.7	8.5	6.8-8.9
Alkalinity (as $CaCO_3$), mg/l			
Phenolphthalein	0	4	0
Methyl orange	159	57	68
Total Solids, mg/l	234	129	160
Total Dissolved Solids (TDS), mg/l	229	124	149
Total Suspended Solids (TSS), mg/l	5	5	11
Non-CO_3 Hardness (as $CaCO_3$), mg/l	1	9	29
Total Hardness (as $CaCO_3$), mg/l	148	54	75
Chloride, mg/l	11	12	15
Sulfate, mg/l	23	19	15
Sodium, mg/l	23	-	-
Calcium, mg/l	48	-	-
Magnesium, mg/l	7	*	*

*Calcium/magnesium ratio of 6 remains unchanged through treatment.

and, depending on demand, water from one water stream may flow back into the industrial reservoir on its way to the next tier of water usage.

Though KSC has the best water usage record, its water quality data for individual plant units are neither specific nor extensive. The additional water quality data available are for cooling tower waters. Analyses of the four major system streams, from the highest to the lowest, are given in Table 4.

Data in Table 4 show how significantly water quality degrades with use. TDS builds up by about an order of magnitude between streams 1 and 4. Chloride increases approximately 20-fold, hardness 9-fold, and sulfate 7- to 8-fold.

Even with this system there are some areas where equipment problems have been encountered. At the tin mill, reverse osmosis (RO) is used where the TDS is brought down from domestic water supply level of 150 to 5 mg/1. The TDS buildup interferes with the emulsion stability, and before the use of RO, the emulsion had to be thrown out in a couple of days creating a significant pollution problem. At present, the emulsion is stable for a couple of weeks. From this one example, it becomes clear that application of existing technology at the proper areas can significantly reduce the water pollution problem.

Only a few cases of effect of water quality on product quality were identified during the discussion. Speck rust on cleaned and oiled plates was initially thought to arise from poor water. But now it is considered to arise from water droplets from the nearby scrubber, carrying traces of acid.

In an indirect manner, oily mill scale sludge is a water quality problem. Because the adhering oil to the mill scale cannot be easily separated, its use at the sinter plant is hindered. If used, the burning creates an air pollution problem--a blue haze. Proper water treatment of the scale-laden water should provide a solution to the problem.

Recovery of chromium from plating waste will be desirable, both for use of chromium and reuse of the water. However, at present, lack of proper technology compels KSC to dump them in solar ponds where, in a few years, natural concentration from 20 mg/1 to 16 g/1 may enable them to recover chromium.

From the viewpoint of this task, not much information regarding water quality at specific units was obtained. KSC has extensive information on incoming water and cooling tower water analysis, and follows a practice which may be considered the best in the world. However, it is to be remembered that in spite of this exemplary practice, the flow rates shown for all streams are based on calculations. We were given to understand

TABLE 4. ANALYSES OF WATER OF THE FOUR MAJOR WATER STREAMS, KAISER STEEL CORPORATION

Quality Level	Use	pH	TSS, mg/l	TDS, mg/l	Hardness, mg/l	Total Alkalinity, mg/l	Chloride, mg/l	Sulfate, mg/l
1 (highest)	Non-contact cooling	7.4	23	283	108	51	53	49
2	Rolling mills	7.7	50	300	120	70	50	70
3	Blast furnace Steelmaking Sintering Coke ovens	7.3	39	550	200	50	170	100
4 (lowest)	Blast furnace gas cleaning	7.1	50*	3000	900	220	1100	370

*Can be as high as 300 mg/1.

that in the entire plant there may not be more than three water flowmeters in operation. Thus, one significant data gap at KSC is simply lack of adequate flow information. This data gap coupled to absence of water analysis for individual plant units makes it difficult to predict additional gains that can be made in the use of a different flow rate and/or water quality to obtain the same high quality end product now being obtained.

ARMCO STEEL CORPORATION (ASC)

Using water on an average of 25 times, ASC had drastically reduced its water usage. As shown in Table 5,[15] a consumption of 2400 l/min (6240 gpm) amounts to 96% recycling and 6000 to 8000 liters of effluent per tonne of steel.

ASC draws water from the Miami River and, after settling and holding in ponds, the make-up water is lime-softened and distributed as shown in Fig. 7. Thirteen separate recirculated water systems are used. All wastewater flows through a storm sewer system to Dicks Creek, a small tributary of the Miami River. During the hot, dry summer months, the natural flow in the creek dries up, leaving ASC waste as the only water source. In order to prevent fish kills during the low flow periods, all wastewater is of sufficient quality to support fish life without dilution. A simplified diagram of the wastewater system is shown in Fig. 8. Seventeen water conservation and wastewater treatment systems were installed. Typical analyses of discharge to Dicks Creek at Outfall Nos. 002 (BF and Coke Ovens), 003 (OH), 005 (Primary Mills), and 641 (Pickling) are given in Table 6.

Outfall 003 has high zinc because the open hearth shops use a large amount of galvanized iron scrap. Also, the significant fluoride content arises from the use of fluorspar for steelmaking

The primary mill operation is reflected in the significant level of oil and grease in Outfall 005. The very large chloride level in Outfall 641 reflects the pickling operation. Outfall 002 is fed by a large volume of non-contact cooling water from the blast furnace complex, and temperature is a significant monitoring indicator.

In Figure 9,[15] the two modern water systems--one for BOF and the other for vacuum degassing and continuous casting--are shown. The entire BOF shop discharges only 190 l/min (50 gpm) of effluent. Of course, significant evaporation losses occur at the cooling tower. The original concept was to use boiler quality water in a totally closed cooling system because the temperature rise in the hood, duct, and lance cooling is very high, 60°F. On economic grounds, this concept was changed to use of lime-softened water and open air cooling towers with excellent results. The normal blowdown of 95 l/min (25 gpm) results in five to six cycles of concentration. Dissolved solid levels reach 1500 mg/l or higher without noticeable scaling or corrosion problems.

TABLE 5. MILL WATER DISTRIBUTION AND BLOWDOWN, ARMCO STEEL CORPORATION[15]

Production Area	Make-up,* l/min	Total Water Used Recirculated and Once Through, l/min	Blowdown, l/min
Coke plant	3,800	38,000	3,000
Blast furnace	3,800	87,000	2,900
Open hearth shop	4,200	95,000	1,100
Basic oxygen shop	1,100	62,000	190
Vacuum degasser	12,500	12,500	To continuous caster
Continuous caster	(12,500)	57,000	To hot mill
Soaking pits and slab furnaces	1,900	91,000	To hot mill
Hot rolling mill	(12,000)	265,000	9,500
Picklers	3,000 (750)	3,800	3,800
Cold rolling mill	2,600	700,000	1,900
Annealing furnaces	(1,100)	1,100	1,100
Coating line	280	5,300	110
Total	33,000	790,000	24,000

* Parentheses indicate blowdown from another system.

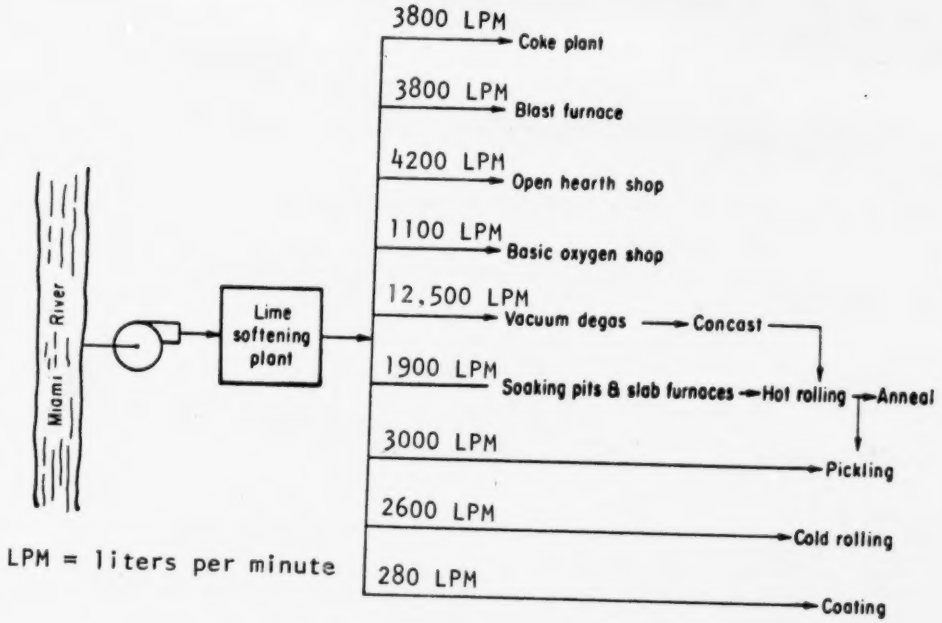


Figure 7. Water supply and distribution to major production areas, Armco Steel Corporation.(15)

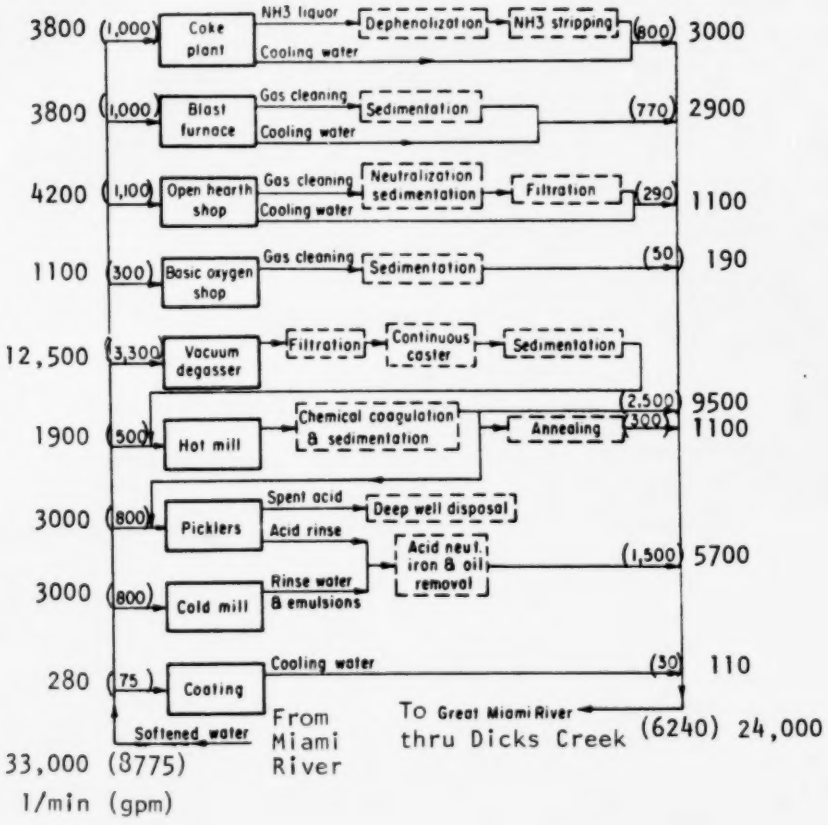
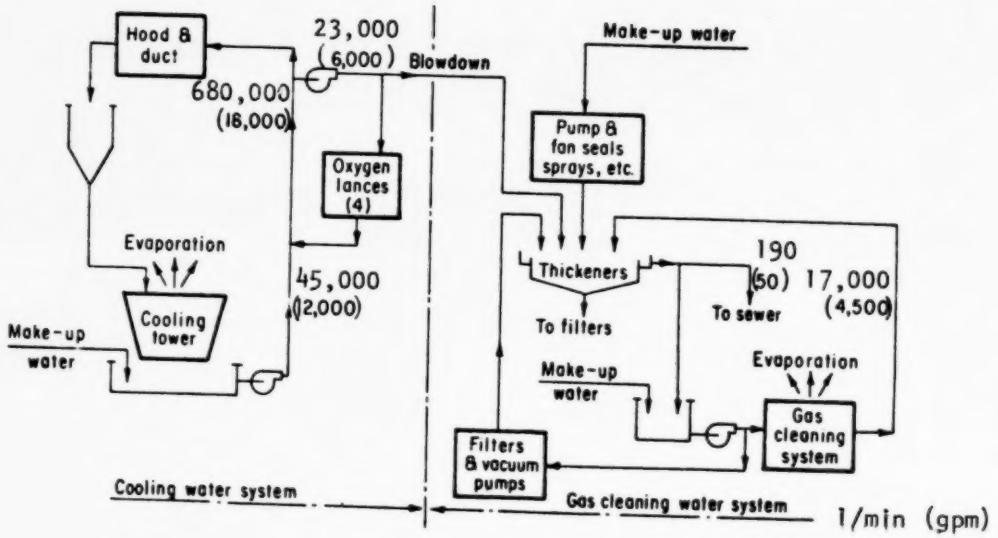


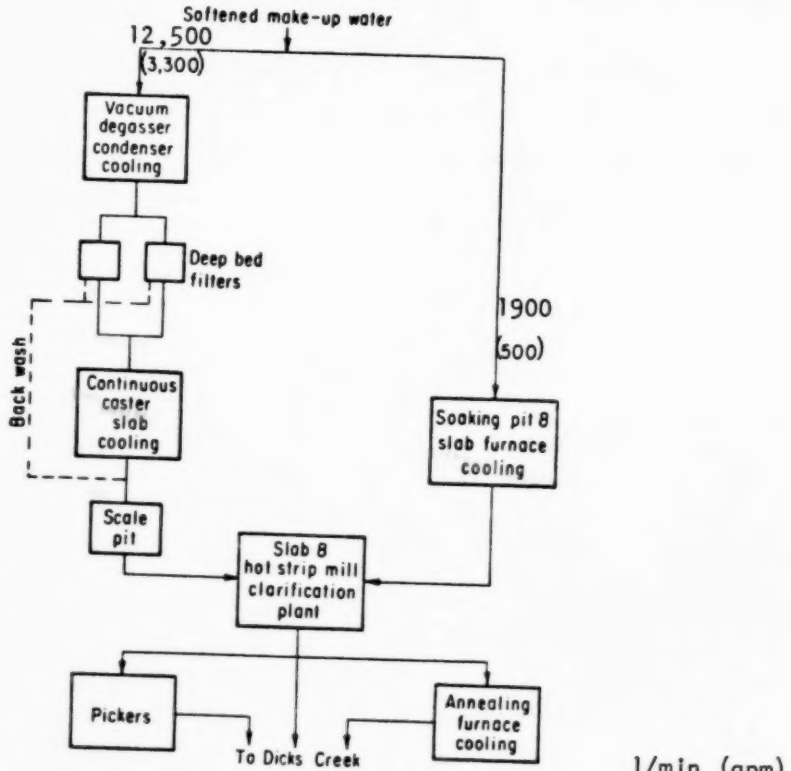
Figure 8. Simplified schematic of the wastewater system, Armco Steel Corporation.(15)

TABLE 6. AVERAGE ANALYSIS OF EFFLUENTS TO DICKS CREEK, ARMCO STEEL CORPORATION, PERIOD 10/1/77 TO 10/31/77[15]

Parameter	Analysis at Outfall No.			
	002	003	005	641
TSS, mg/l	-	38.6	17	2
Total iron, mg/l	-	-	-	0.222
Dissolved iron, mg/l	-	0.032	0.05	0.105
Fluorides, mg/l	-	16.9	-	-
Chlorides, mg/l	-	-	-	541
Total zinc, mg/l	-	55	0.053	0.077
Lead, mg/l	-	0.427	-	-
Oil and grease, mg/l	-	-	4.5	-
pH	7.9	7.56	8.45	8.2
Flow, 10^6 liters/day	3.8	3.3	2.5	8.7
Temperature, °C (°F)	21 (70)	-	-	-



(a)



(b)

Figure 9. Steel melt shop water system, Armco Steel Corporation.(15) (a) BOF is served by two separate water systems discharging only 190 l/min (50 gpm). (b) Vacuum degassing and continuous casting waters are reused.

From this it is realized that process water at the BOF shop can tolerate a high TDS level. How high this level can attain--with proper chemical treatment to prevent scaling--can only be determined after a sustained operation at different high levels. Obviously, the plant operators will be unwilling to take such risks to determine the limit of equipment/chemical capabilities in controlling scaling problems just to determine the water quality limitations for any piece of equipment, though this information may enable them to further reduce discharges.

Figure 9b shows how the very large volume of water required for vacuum degasser and continuous casting units are reused in the primary mills.

A perennial problem is treatment of spent pickle liquor. At ASC, at the terminal waste treatment plant, the spent pickle liquor is disposed of by deep oil injection. All other acid and oily wastes are combined and treated. The oily mill scale sludge also causes blue haze when burned (as at KSC) and is dumped at present. It is expected that after several years of exposure it may be usable in the sinter plant.

Very little specific data on water quality and quality-related product problems were available at ASC. The familiar problem of speck rust and carbon spots on flat products (mentioned at KSC) are also evident at ASC. Unlike KSC, at ASC they feel that speck rust is due to high dissolved solids (chlorides) in the water. They are studying this problem by changing from river water (TDS 70 to 220 mg/l) to well water (<30 mg/l). They are working on temperature/humidity control, and increase in oiling of pickled sheets.

COLORADO FUEL & IRON STEEL CORPORATION (CFI)

This 100-year-old plant is established in a semi-arid region at Pueblo, Colorado, where water rights are very precious and more people were killed for stealing water than for stealing horses! The plant water is taken from the Arkansas River 40 km (25 miles) west of Pueblo. It is conducted by a 74 km (46 mile) long canal to large storage reservoirs located about 7 km (4 miles) from the plant. The transportation causes 15% loss of water taken from the river. Thus, out of a typical 330×10^6 l/day (87 MGD) water taken out of the river, about 280×10^6 l/day (75 MGD) is received at the reservoirs, as shown in Fig. 10.

The effluent is discharged into Salt Creek, a natural flow channel lying almost entirely within CFI property. Typically, about 197,000 l/min (52,000 gpm) of water is discharged. In other words, the entire 280×10^6 l/day (75 MGD) taken in is discharged though some local recyling of water is carried out. On an average, water amounting to 71,000 l/tonne (17,000 gal/ton) of steel is used for a production level of 1.45 million tonnes/

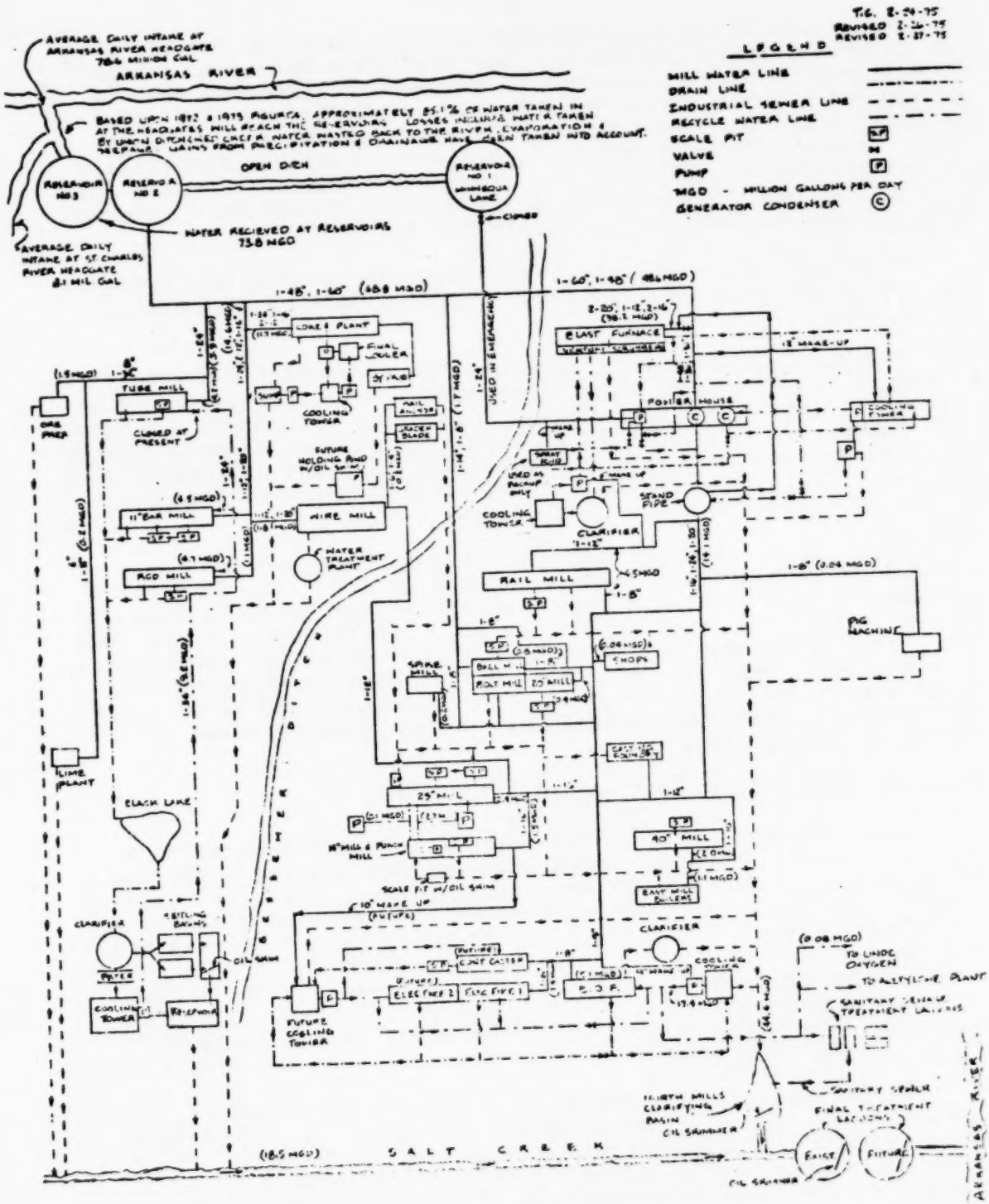


Figure 10. Mill water distribution, Colorado Fuel & Iron, 1974.

year. The Arkansas river becomes totally dry after the entire river flow has been intercepted by the city, CFI, and other "owners." The river becomes a river again below Pueblo, composed entirely of the sewage outfall of the community and the steel mill. Thus, the situation at CFI is different from other steel plants. The 280×10^6 l/day (75 MGD) intercepted by CFI is returned fully so that downstream there will exist a river for others to tap. The quality of the returned water, however, is extremely important, and CFI ensures that it is of high quality with fish thriving in the holding lagoons.

Analysis of plant influent for 1976 is given in Table 7 (data provided by CFI). Certain special features of this analysis may be noted. This area of Colorado has many mineral deposits and the high lead and associated arsenic, as well as fluorides, reflect that condition.

The October 1977 average, maximum, and minimum analyses of plant effluent are given in Table 8. Again, the high level of lead and zinc may be noted. The quality criteria [16] for water indicate that cyanide, phenol, and mercury are in excess. The source of mercury may be from the coal washery. CFI is one of a few steel plants which have a coal washery within the plant boundary, and large lagoons have been established to settle the coal fines.

No information was available regarding effect of water quality on product quality. The simplified material flow diagram in Fig. 11 shows the nature of end products (no cold rolled sheet or coated products), and these are virtually not affected by water quality.

DISCUSSIONS WITH GROUPS AND INDIVIDUALS

In this category, the following activities may be listed:

1. Discussion with AISI Environmental Committee
2. Discussion at Hydrotechnic Corporation
3. Discussion with Mr. Walter Zabban, The Chester Engineers, Pittsburgh, Consultant

American Iron and Steel Institute (AISI)

AISI is a trade association for the steel industry and is located in Washington, D.C. At the beginning of this study, a meeting was arranged with Mr. W. Benzer, who is in charge of the AISI Environmental Committee. In this meeting, Mr. Benzer was helpful and gave copies of several studies sponsored by AISI on Pollution Control in the Steel Industry.

TABLE 7. ANALYSIS OF PLANT INFLUENT (1976), COLORADO FUEL & IRON

Parameter	Analysis		
	High	Low	Average
Alkalinity, mg/l	129	50	100
Ammonia (N), mg/l	0.46	<0.1	0.1
Nitrate (N), mg/l	0.1	0.1	0.1
Chloride, mg/l	12	<1	6.8
Sulfate, mg/l	181	82	105
Dissolved solids, mg/l	313	226	270
Suspended solids, mg/l	23.9	4.38	13.4
Oil and grease, mg/l	3	<1	2.3
Arsenic, µg/l	20	<5	9.6
Copper, µg/l	40	<5	5.7
Fluoride, µg/l	680	410	53
Iron (dissolved), µg/l	480	10	143
Lead, µg/l	30	<10	18

TABLE 8. ANALYSIS OF PLANT EFFLUENT FOR OCTOBER 1977, COLORADO FUEL & IRON

Parameter	Analysis			Quality Criteria(16)
	Min	Max	Average	
Temperature, °C	18	23	-	
Dissolved oxygen, mg/l	3.5	5.6	4.9	
BOD_5, mg/l	2.9	6.1	4.2	
pH	7.7	8.4	-	
TSS, mg/l	5	14	8	
Oil and grease, mg/l	1	10	3	
Ammonia (N), mg/l	1.4	3.6	2.0	
Cyanide, mg/l	0.044	0.222	0.110	0.005
Chloride, mg/l	-	18	-	
Sulfate, mg/l	-	185	-	
Arsenic, µg/l	-	<0.1	-	50
Iron (dissolved), µg/l	<20	30	30	
Lead, µg/l	<40	40	<40	50
Zinc, µg/l	60	350	220	5000
Phenol, µg/l	<3	57	7	1
Mercury, µg/l	-	<0.4		2*

*0.05 and 0.1 µg/l for fresh water aquatic life and wildlife and for marine aquatic life, respectively.

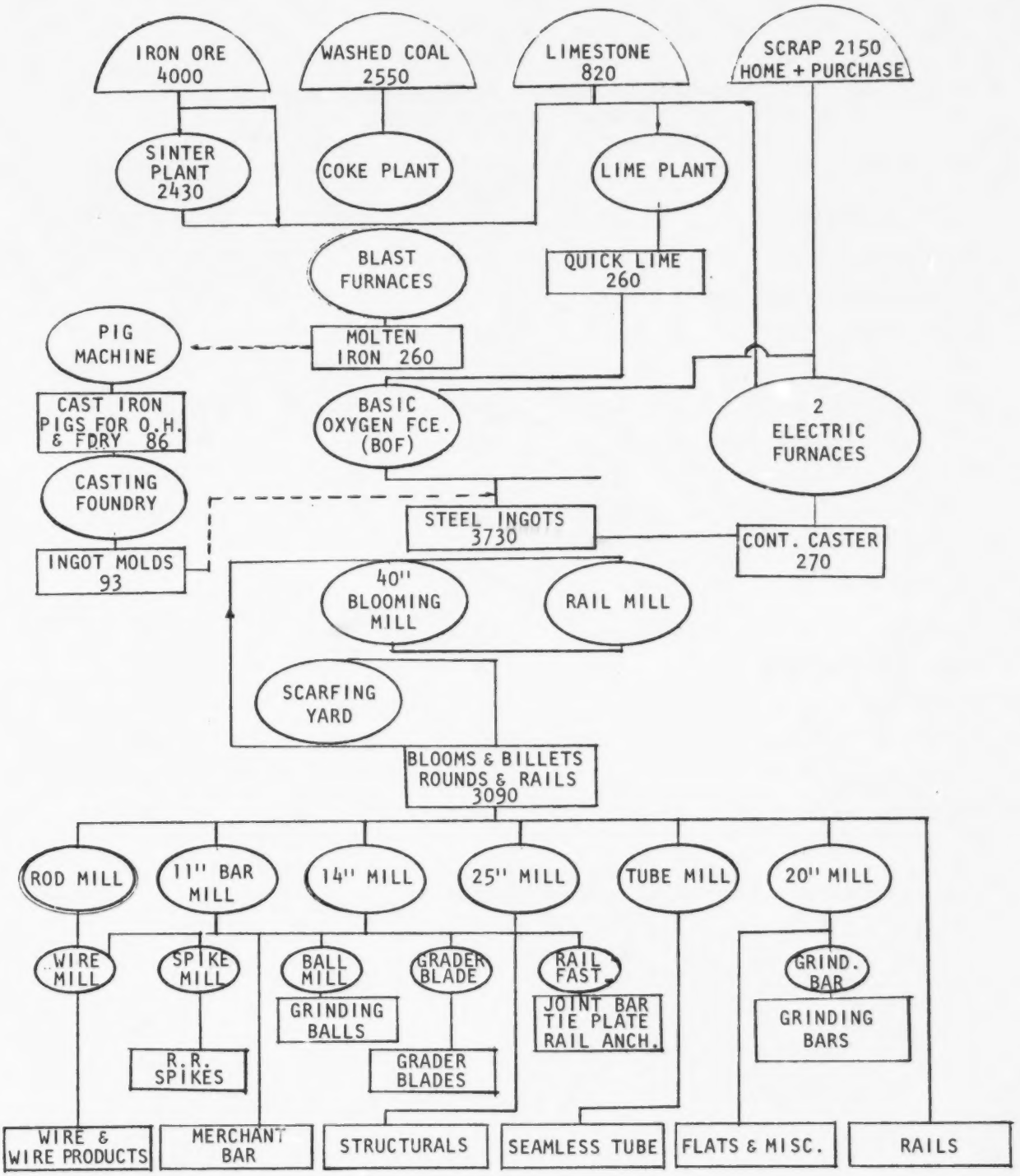


Figure 11. Simplified material flow diagram, Colorado Fuel & Iron Pueblo plant. Average daily (365 days) tonnes in 1971.

A couple of months later, a meeting with the full AISI Environmental Committee took place where the EPA Project Officer, Mr. Ruppersberger, was also present.

While trying to be helpful, AISI did not agree to refer our requests for information to any steel plant. They felt that enough information had already been supplied to EPA and that this should be sufficient and utilized. Any steel plant approach to be made by IITRI on this program had to be strictly on an individual basis.

Dr. S. C. Caruso, of the Mellon Institute, Carnegie Mellon University (CMU) was present at the meeting. CMU has been associated with AISI for many years on conducting studies on pollution, and at our request AISI agreed to release several volumes of studies completed so far.[17, 18] These studies do not directly relate to this task.

Hydrotechnic Corporation, New York

Hydrotechnic (HC) is, at present, involved in a study for EPA. The study is entitled "Integrated Steel Plant Pollution Study for Zero Water and Minimum Air Discharge." A visit was made to their office.

HC is studying water discharges from the following integrated steel plants:

1. Kaiser Steel, Fontana (KSC)
2. Youngstown Sheet & Tube, Indiana Harbor (YSTIH)
3. Inland Steel, Indiana Harbor (ISIH)
4. United States Steel, Fairfield (USSF)
5. National Steel, Weirton (NSW)

The thrust of HC's study is on zero-discharge. For this, HC is compiling accurate information on flow rates, evaporation losses, and recycling. They are marginally concerned with water quality, and very few data were available from them.

The KSC water quality data shown earlier in Table 4 were from the Hydrotechnic study: Tables 9 to 11 give the data available from Hydrotechnic on the three other steel plants. The data are very meager and show that only a few types of water qualities are used in these plants. No information was available from these steel plants through HC on the effect of minimum water quality on product quality.

TABLE 9. WATER ANALYSIS, NATIONAL STEEL CORPORATION, WEIRTON

Quality	Water Use	TSS	TDS	Hardness (Al_2O_3)	Alkalinity (Methyl orange)	Total Alkalinity, ($CaCO_3$)
1	Non-contact cooling Runout table sprays on hot strip mill Cold rolling mills Pickle lines and other facilities	37	--	--	--	
2	Plating lines	--	--	34.2	47.9	
3	Boiler house	<1	2250	--	--	50-100

For Quality 1: Na = 20 mg/1, phenol = 15 µg/1, CN^- = 37 µg/1, BOD = 3.0, ammonia (N) = 800 µg/1, nitrates = 0.7 mg/1, sulfates = 78 mg/1

For Quality 3: Silica = 25 mg/1.

All other data are in mg/1.

TABLE 10. WATER ANALYSIS, U.S. STEEL FAIRFIELD WORKS, ALABAMA

Water Use	Analysis, mg/l				
	TDS	TSS	Oil and Grease	Chlorides	Sulfates
1. Runout table sprays and pickle liquor dilution water	175	25	10	--	--
2. Non-contact cooling, cold rolling mills, plating lines, pickle liquor rinse water, and other facilities	175	25	10	15	30

TABLE 11. WATER ANALYSIS,* YOUNGSTOWN SHEET & TUBE, INDIANA HARBOR

Item (All in mg/l except pH)	Hot Rolling Mills, Strip Cooling, Pickle Dilution and Rinse	Cold Rolling Mills	Non-Contact Cooling†
pH	6.2-9.0	7.0-11.4	
TDS	450	565	300
TSS	40	14	10
Oil and grease	21	7	
Chloride	61	25	
Sulfate	143	254	
Phenol	0.03	<0.01	
NH_4 (total)	3.5	0.10	
CN (total)	0.11	0.12	
Zinc	0.20	0.30	
Cr (total)	0.04	<0.01	
Lead	0.06	0.03	
Iron (dissolved)	0.63	0.26	
Iron (total)	11.4	1.30	
Hardness (total Ca) as $CaCO_3$			100-150
Alkalinity as $CaCO_3$			0-90

*Worst quality that can be tolerated.

†Should not exceed Langelien Index for scaling potential. Values in table are preferred by plant. However, plant uses intake water on a once-through basis.

Discussion with Walter Zabban

Mr. Zabban, Chief Engineer, The Chester Engineers, is a very knowledgeable person on water quality in the steel industry. He was visited several times. His knowledge on various water treatments was very helpful to other tasks. On this task, he could only provide general guidelines regarding the effect of water quality on problems to be encountered in equipment maintenance and the best available treatment to improve water quality.

INFORMATION FROM EQUIPMENT AND WATER CHEMICAL SUPPLIERS

The few equipment manufacturers who responded to our inquiries have the following two general observations to make:

1. The equipment is rugged in design and can accept a wide range of water quality with modifications made by suitable chemicals, where needed.

2. The equipment is made to customers' water specifications.

A response from Koppers Engineering and Construction, a major coke oven and by-products plant supplier, was also obtained. Without specifying any quantitative data, the general philosophy of water quality was mentioned - soft water, low chloride, temperature limitations, low suspended solid content, and adequate blowdown for scale control.

Morgan Construction Co., a supplier of rolling mills, states that they do not issue any rigid water specification but a guideline. For example, pH to be 7.0, chloride <100 mg/l, sulfates <300 mg/l, TSS <25 mg/l, and largest suspended particle to be less than 250 μm (0.010 in.).

Loftus Engineering Corporation, an engineering and construction firm, replied to the effect that they seldom had an opportunity to specify water quality for their clients because available water had to be used. Cooling water temperature is limited to 32°C (90°F). Due to the size of equipment, large suspended particles are acceptable; and in the event of scaling, sediment, or fouling occurring, the client takes the necessary steps to alleviate the problem.

Continuous casting mold cooling water requirements have been critically analyzed in the literature because even a trace of scaling inside the mold may change the heat transfer coefficient significantly, resulting in a serious molten steel breakout from the thin enclosing solidified shell. Some of the various deposits encountered in a continuous casting mold are shown in Table 12.[19] With proper zeolite softener operation,

TABLE 12. MOLD DEPOSITS IN CONTINUOUS STEEL CASTING (19)

Deposit	Analysis, %		
	Case I	Case II	Case III
Silica as SiO_2	4	1	4
Iron as Fe_2O_3	1	85	8
Loss on ignition	7	9	29
Phosphate as P_2O_5	7	-	28
Calcium as CaO	48	-	16
Magnesium as MgO	2	-	7
Carbonate as CO_2	31	-	-
Zinc as ZnO	-	-	-
Chromate as Cr_2O_3	-	5	4

Case I - Calcium carbonate scale; poor softener operation (closed system)

Case II - Migratory corrosion products (closed system)

Case III - Severe hydraulic fluid leaks (open recirculating tower system)

and changing from recirculating tower system to a closed loop operation, infiltration of the system by oil, grease, hydraulic oil, and suspended solids is prevented. Closing the system also minimizes inhibitor consumption. Chromate-type inhibitors are recommended, but nitrates can be used. Phosphate and zinc-bearing inhibitors are to be avoided since either will rapidly plate out on mold surfaces and cause breakouts.

In continuous casting, the spray water system is often the dirtiest and--combined with airborne contamination, corrosion, and fouling, normally associated with open air cooling tower systems--presents possible problems as shown in Table 13. With proper design of the water system, all the problems can be totally overcome.

FOREIGN STEEL PLANTS

Hoesch iron and steelworks located on the eastern fringe of the Ruhr district in West Germany has installed modern water recirculation systems for its 1727 mm (68 in.) hot strip mill. As a result, the system requires only 1100 liters (290 gallons) of make-up water per tonne of steel produced.(20)

The Hoesch water systems (as shown in Fig. 12) are designed for reuse at various facilities. The quality of wastewater is restricted to that involved in the sludging operation and by faults in the individual systems.

Long-term analyses have shown that cost of recirculated water is substantially lower compared with nonrecirculating systems, in spite of additional depreciation and maintenance costs. The total installed pump rating is about 20,000 kw.

Their investigation has also shown that investment cost of sea water cooling systems in new plants located directly on the North Sea is considerably higher than that of their system.

After a thorough comparative analysis of capital costs, maintenance and operational problems of evaporation cooling with steam generation, and cooling tower system, Hoesch opted for evaporation cooling. Evaporation cooling system offers economic advantages under the following basic conditions:

1. The large volume of steam generated must be accepted by the existing steam mains and used in the blast furnace area or power-generating station.

2. Where fuel costs are high and investment costs are low, the evaporation system is definitely advantageous.

TABLE 13. CONTINUOUS STEEL CASTING PROBLEMS [19]

Problem Area	Solutions
Migratory corrosion products	Effective corrosion inhibitor program Use of stainless steel spray headers
Scale and suspended solids	Improved scale pit & filter plant operation Use of polymeric/phosphonate dispersants
Oil	Effective use of oil skimmers & filters Use of surfactants Improved housekeeping--minimize hydraulic fluid and oil leaks
Biological fouling	Effective use of proprietary biocides
Miscellaneous foreign debris	Improved housekeeping practices Consistent operation of filter equipment

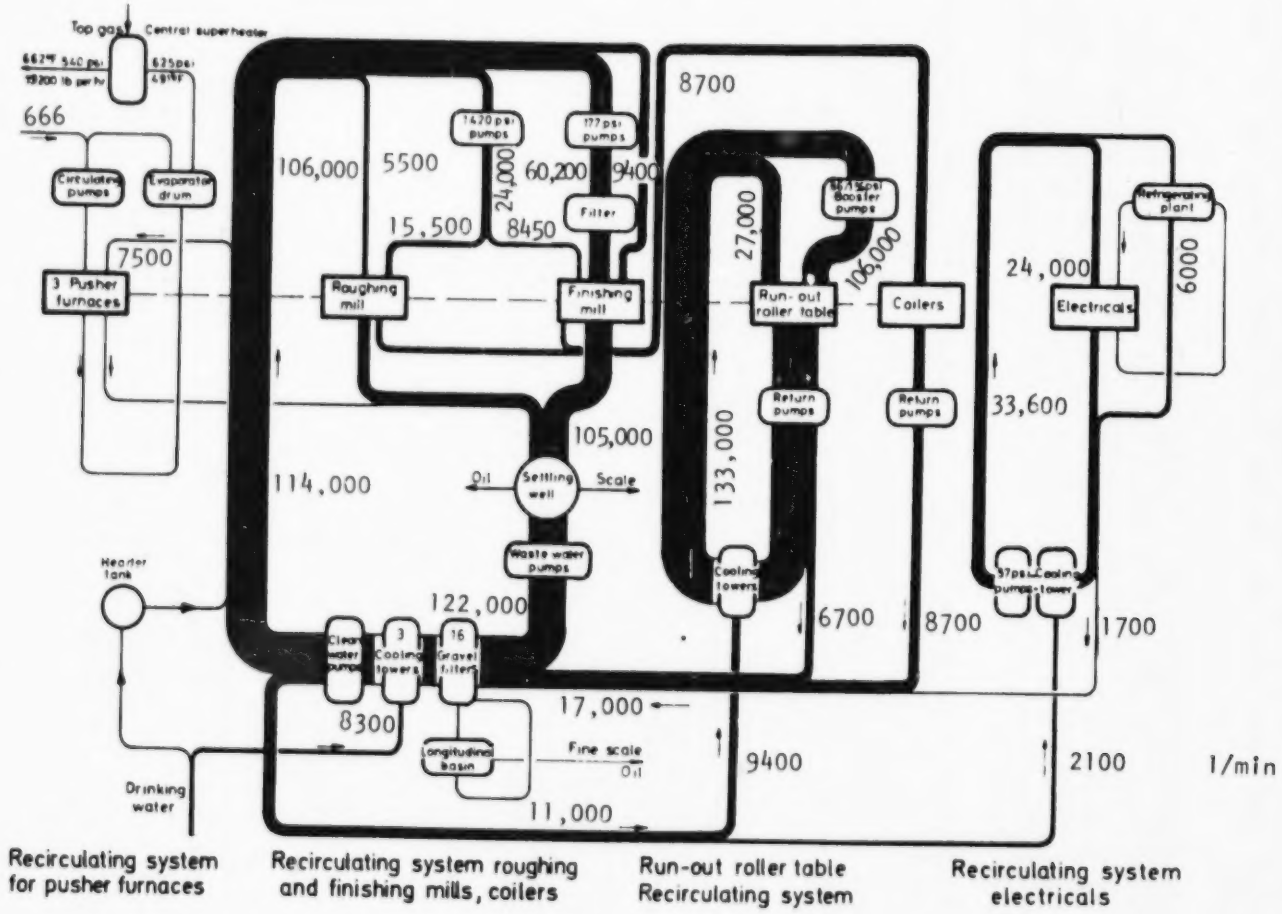


Figure 12. Strip mill cooling water recirculation systems, Hoesch Hüttenwerke, Dortmund, West Germany.(20)

In addition to paying water cost for drinking water, Hoesch had to pay a wastewater fee of DM 0.21/1000 liters, i.e, about $0.40/1000 gallons. With the newly installed recirculation system, the water cost was reduced to DM 0.10/1000 liters or $0.19/1000 gallons.

The permissible degree of rolling mill contamination is given in Table 14. On the basis of 1210 liters/tonne (290 gallons/ton) of hot strip, the third column in Table 14 shows the ppm values as g/tonne and compares with the fourth and fifth columns which are, respectively, the BPCTCA (1977) and BATEA (1984) effluent guideline data. Hoesch's permissible values are better than 1984 guideline data.

In the USINOR's Dunkirk plant in France, [21] for an output of 6000 tonnes/day (2 million tonnes/year) a makeup water of 0.9 to 1.0 million liters/hr is needed, which is equivalent to 3600 to 4000 liters/tonne of steel. As mentioned earlier, at the 8 million tonne/year stage the water requirement will be almost half of 4000 liters/tonne.

At the Dunkirk plant, the fresh water coming from Dourbourg Canal is decanted, heated with ferric chloride, softened with lime, filtered, and chlorinated. Some water is further softened by ion exchange. Table 15 gives the individual unit requirements.

With 98.5% recycling, the ARBED[22] plant water (Luxemburg) requires 2500 liters/tonne (2.5 m^3/ton) of steel; 53% is used in the blast furnaces, 32% in the steel plants and rolling mills, and 15% in the power station and for miscellaneous uses.

Four separate water circuits are used: one for BF and sinter plant, second for BF gas cleaning, third for power station, and fourth for mills and other uses.

RECYCLING OF STEEL PLANT WASTES AND ITS RELATIONSHIP TO WATER USAGE

There is mounting pressure as well as increasing interest in the recycling of every unit of iron-bearing material generated within the plant perimeter. This waste recycling is related to water recycling, both physically and technologically. At the many plants of the British Steel Corporation,[23] about 2.4 million tonnes of waste was estimated to arise in 1975, as shown in Table 16. This quantity amounts to about 10% of raw steel production.

The properties of collected waste must fit the units that will consume it. These properties depend on (1) form of collection, (2) the particle size distribution, and (3) the chemical analysis.

TABLE 14. PERMISSIBLE IMPURITIES IN INDUSTRIAL WASTEWATER FROM ROLLING MILLS, HOESCH IRON & STEEL WORKS, DORTMUND, WEST GERMANY[20]

Item	Permissible Quality, Dortmund		EPA Guideline Hot Forming Flat, Category "O" - Hot Strip†	
	ppm*	g/tonne†	BPCTCA (1977)	BATEA (1984)
Temperature	30°C (86°F)			
pH	6.5-9.5		6.0-9.0	6.0-9.0
Settling materials (TSS)	1.0	1.0	1.1461	0.0156
Total chromium	4.0	4.0		
Copper	3.0	3.0		
Nickel	5.0	5.0		
Zinc	5.0	5.0		
Cyanides	1.0	1.0		
Oil streaks	0	0		
Oil and grease (petroleum ether extraction)	5.0	5.0	0.3438	0.0063
Total iron	No limit			

*Except temperature and pH. 1 ppm = 1 g/tonne.

†Based on 1,200 liters/tonne (290 gallons of effluent/ton) of steel.

TABLE 15. UNIT REQUIREMENTS FOR WATER, USINOR, DUNKIRK, FRANCE[21]

Process Unit	Water Need, 1000 l/hr	Cooling Towers
Blast furnaces		
Cooling	4,000	1 cooler of 4×10^6 l/hr
Filtering of the gases	3,600	1 cooler of 4×10^6 l/hr
Steel works		
Cooling of the hoses	200	
Cooling of the smokes	100	
Scrubbing of the gases	1,500	1 cooler of 1.5×10^6 l/hr
Rolling mills		
Cooling of the motors	1,100	1 cooler
Rollers (stabling and quarto)	1,550	1 cooler
Descaling	450	
Strip rolling train		
Cooling of the motors	3,000	1 cooler
Train, furnaces, and descaling	2,000	1 cooler
Total	25,000	

TABLE 16. SOURCES AND RATES OF PRODUCTION OF IRON-BEARING WASTES, BRITISH STEEL CORPORATION (BSC), 1975[23]

Source	Normal Rates of 'Production' (dry basis)	Estimated Quantities Arising within BSC in 1975, tonnes
Sinter plant dust	20-40 kg/tonne sinter	300,000
Blast furnace dust (dry	10-20 kg/tonne hot metal	200,000
Blast furnace dust (wet)	10-20 kg/tonne hot metal	180,000
Basic oxygen steel fume	7-15 kg/tonne steel	180,000
Electric arc furnace fume	10-20 kg/tonne steel	40,000
Slag metal recovery:		
Ironmaking	∿10 kg/tonne hot metal	150,000
Steelmaking	∿15 kg/tonne steel	380,000
Mill scale	20-60 kg/tonne steel	930,000
Pickling acid residues	5-10 kg/tonne steel	30,000

The form of collection is intimately associated with water treatment and recycling facilities of the plant. The initial water content of the wastes is normally either very low (<5%) or very high (>90%). Some wastes are collected dry, others by wet scrubbing. Reduction of >90% to 70% water is usually carried out in thickeners, and the underflow is either allowed to settle and dry (requiring large land areas and, being at the mercy of the weather, is not preferred) or filtered to a cake containing 15 to 30% moisture. The technology is available and can be coupled to water recycling solutions.

Particle size in the wastes varies widely between processes, as shown in Fig. 13. Also, it depends on collection technique, dry vs. wet, and is thus related to water recycling. Apart from the coarse mill scales, none can be recycled directly. The wastes cited in Fig. 13 do not include iron-units that are associated with waste pickle liquor generation and recycling.

Chemical analyses of the wastes, particularly their tramp element contents, may pose problems to their recycling and indirectly affect water recycling. The wastes usually have the following groups of metals and minerals:

1. Valuable reusable materials (Fe, Mn, C)
2. Slag/gangue materials (CaO, SiO_2, Al_2O_3, MgO)
3. Tramp elements (Zn, Pb, S, P, K_2O, Na_2O, Ni, Cu, Sn, Mo)

If chromium plating is used, then Cr-bearing residues will also be generated.

At BSC, sinter plant dust, as well as BF and BOF dusts collected dry, is recycled. The wet collected dusts are dumped, thus wasting valuable water. None of the electric furnace dust, containing high levels of tramp elements, is recycled. Mill scale and slag metallics are recycled. At BSC, out of 2.4 million tonnes of waste, 1.8 million tonnes are recycled.

The study at BSC shows that a complete waste recycling system must be a part of complete water recycling, and a synergistic solution is best for both.

SOME STRIP QUALITY PROBLEMS ASSOCIATED WITH WATER QUALITY

From the foregoing discussion it is clear that very little is known about minimum water quality requirements for each unit steel-making process. Even much less than that is known about the effect of water quality on product quality. The problems of "speck rust" of plates and sheets, and "blue haze" due to sinter plant use of oily mill scale residue were mentioned earlier. Another problem that has come out in the open is strip cleanliness, and corrosion problems of auto body sheets associated with it.

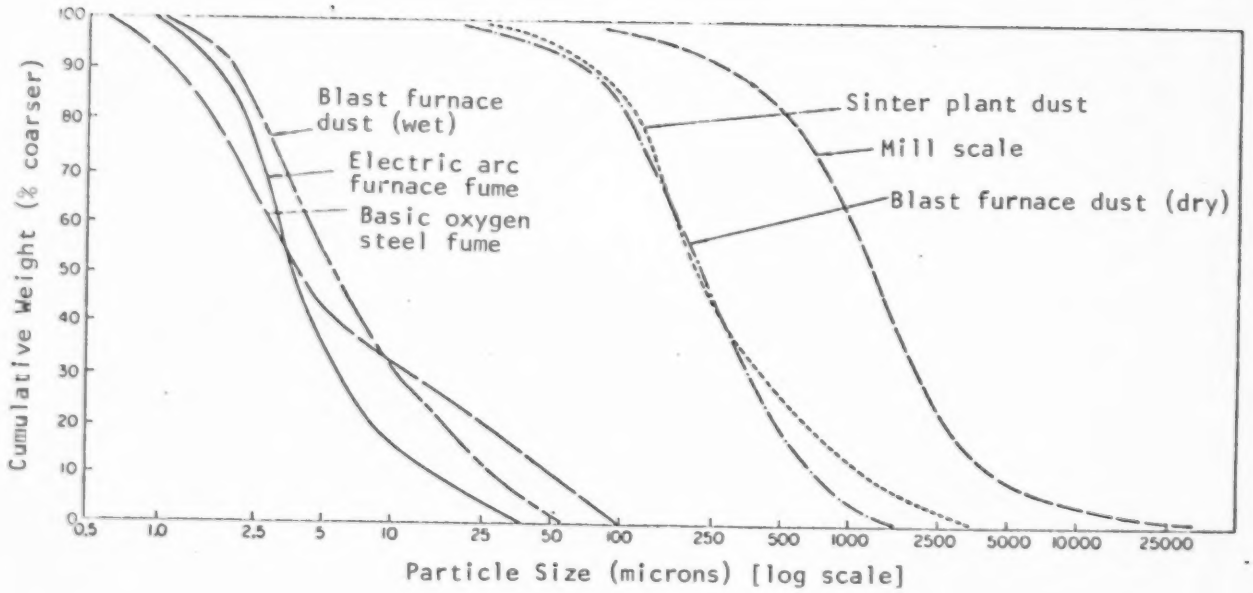


Figure 13. Particle size distribution for representative samples of ferruginous wastes.(23)

In a recent article,[24] GM researchers have speculated that the organic carbon deposits on steel sheets may arise from residues of drawing oil. These residues are remnants of water-oil emulsion used for temper rolling.

In a recent panel discussion on strip cleanliness at the Joint AISE/ASLE Lubrication Session at Cleveland, certain similar problems were discussed. The discussion was off-the-record.

The nature of oil-burn on steel surfaces which appears in cold rolling was related to fatty oil and water on the surface resulting in formation of iron oxide.[25]

SECTION 7

REUSE AND RECYCLING OF WATER IN THE IRON AND STEEL INDUSTRY

The assumption that fresh water is an inherently cheap commodity, abundantly available without effort, was finally laid to rest in the 1970's. Almost 90% of water utilized in the steel industry is nonconsumptive in nature, i.e., the steel mills return them directly to the lakes, rivers, and other water bodies from which they were taken. Of the remaining 10%, 80% of it goes back to the environment in evaporation and returns promptly through rain and snow. Only about 2% may be said to be consumed, i.e., lost with sludge and other waste products and only recycled back to water bodies after prolonged periods. However, that 2% amounts to some 4200 l/tonne (1000 gallons/ton) steel, and a steel production of 136 million tonnes/year (150 million tons/year) means an immediate loss of 570 billion liters (150 billion gallons) of water/year or about 1560 million liters/day (400 million gallons/day). One means of conserving these supplies is by the reuse of water. It is necessary to define the terms reuse and recycling a little more precisely before an evaluation can be made.

Reuse denotes that water is used and returned to a water body for subsequent use by another consumer. If the water body happens to be the sea, then a direct loss of resource will occur.

Recycling implies repeated use of water for the same or successive processes.

The concept of total recycling and zero-discharge must take into consideration:

1. Transfer of pollutant to air, and its control.
2. Solid waste as a pollutant and its recycling.

At present, the future EPA guidelines stipulate a rate of effluent discharge coupled with pollution level. Several steel plants in the USA and abroad are, at present, doing better than 90% recycling and some as high as 98% recycling. On the other hand, some plants may be using water on a virtually once-through basis, though the discharge is treated to meet state and federal regulations. An example is Colorado Fuel and Iron, which draws

about 280 x 10^6 liters/day (75 MGD) and discharges the same amount. With significant recycling, the withdrawal can be considerably lessened, but the amount withdrawn (less evaporation losses) must be returned to the Arkansas River to enable downstream users to have adequate water.

Figure 14 gives a simplified picture of a typical recycle system.[26] Contaminants as suspended or dissolved materials are picked up at a "consuming" point. Water is "lost" from the system due to direct losses, evaporation, or with impurities (sludges) at the treatment stage.

Relationships can be obtained based on water and contamination balances, with the term definitions given in Fig. 14, such as:

$$A = B + L \tag{1}$$

$$B = \frac{Y + CL - D}{R - C} \tag{2}$$

$$R = \frac{AC + Y - D}{B} = \frac{AC + Y - D}{A - L} \tag{3}$$

The basic concept of water conservation by recycling is that (A + V) vol/hr of water can be made available with a make-up supply of A vol/hr. A will be minimized by reducing losses L and by reducing B, the blowdown. B may be reduced, as Eq. 2 shows, by (1) minimizing contamination (Y), (2) maximizing contamination removal (D) by treatment, and (3) operating at the maximum permissible recycle concentration in terms of the total contaminants. It is Eq. 3 that was sought in this task. That is, we were trying to obtain information on water contamination level with which the equipment can operate efficiently and still produce the quality of products demanded of them.

A simple fact of Eq. 2 is that as R approaches C from the high side, B increases significantly. In other words, B can be made a very small value if R is made significantly much larger than C. However, assuming C to be the level of pollution present in water obtained from an acceptable body of water, an R much larger than C cannot be tolerated, or R has to be treated again to bring it down to C level.

Quantitatively, it is doubtful if recycling has much effect on water consumption except that it might be argued that it could lead to overall increases in losses by evaporation. For example, in an open-air cooling system the actual water loss is greater if a proportion of the water is evaporated to provide cooling than if the water is used on a once-through basis--that is, where the sensible heat of the water is increased but no diminution of quantity occurs. Thus, one has to consider closed evaporation cooling systems instead of open-air type, if real saving in water is to be accomplished in repeated and total recycling.

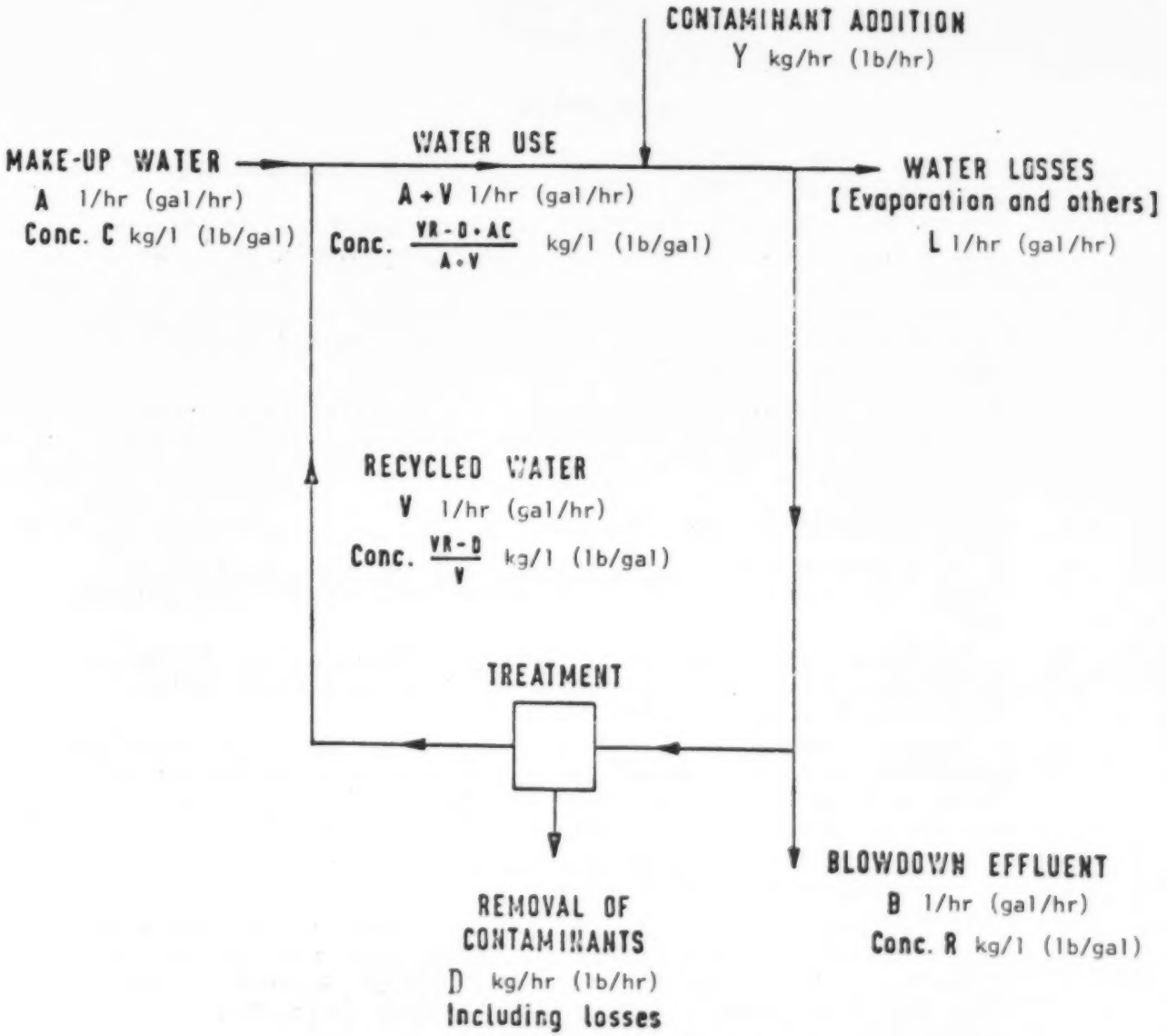


Figure 14. Simplified flow sheet for recycling.[26]

REFERENCES

1. American Iron and Steel Institute, Annual Statistical Report, 1976, Washington, D.C., 1977.
2. Arthur D. Little for the American Iron and Steel Institute, "Steel and the Environment: A Cost Impact Analysis," No. C-76482, May 1975.
3. National Materials Advisory Board, "Trends in the Use of Ferroalloys by the Steel Industry of the United States," NMAB 276, Washington, D.C., July 1971.
4. William Y. Mo and Kung-Lee Wang, "A Quantitative Economic Analysis and Long-Run Projections of the Demand for Steel Mill Products," IC 8451, Bureau of Mines, Washington, D.C., 1970.
5. National Journal, Jan. 14, 1978, p. 55.
6. H. E. McGannon (ed.), The Making, Shaping and Treating of Steel, 9th edition, 1971, U.S. Steel Corporation, Pittsburgh, Penn.
7. G. W. Cook, "Conservation of Water by Reuse at the Appleby-Frodingham Steelworks, Scunthorpe," Iron and Steel International, Vol. 47, October 1974, p. 393.
8. A. Wagner, "Experience Gained in the Iron and Steel Works of Luxemburg by Using Closed Water Circuits and the Effect of These Measures on the Economy and Water Pollution," Iron and Steel International, Vol. 47, No. 3, June 1974, p. 235.
9. M. Huysman, "Reduction in the Amount of Water Used in USINOR's Dunkirk Plant," ibid., p. 236.
10. U.S. Environmental Protection Agency, "Development Document for Proposed Effluent Limitation Guidelines and New Source Performance Standards for the Steel Making Segment of the Iron and Steel Manufacturing Point Source Category," Washington, D.C., January 1974.
11. U.S. Environmental Protection Agency, "Development Document for Advanced Notice of Proposed Rule Making for Effluent Limitation Guidelines and New Source Performance Standards for the Hot Forming and Cold Finishing Segment of the Iron and Steel Manufacturing Point Source Category," EPA-440/1-75/048, Group I, Phase II, Washington, D.C., August 1975.

12. U.S. Environmental Protection Agency, "Development Document for Interim Final Effluent Limitation Guidelines and Proposed New Source Performance Standards for the Forming, Finishing and Specialty Steel Segments of the Iron and Steel Manufacturing Point Source Category," Vols. I and II, EPA-440/1-76/048-b, Group I, Phase II, Washington, D.C., March 1976.

13. Hootie Rugge, Kaiser Steel Corporation, "Kaiser Steel Water Use and Reuse," July 21, 1976, private communication.

14. Robert D. Wight, "How It's Done at Kaiser," The Bulletin, Vol. 8, No. 4, 1972, p. 15.

15. J. Thompson, "Water Pollution Control Program at Armco's Middletown Works," Iron and Steel Engineer, Vol. 49, No. 8, August 1972, p. 43.

16. U.S. Environmental Protection Agency, "Quality Criteria for Water," EPA-440/76/023, Washington, D.C., July 1976.

17. G. M. Wong-Chong and S. G. Caruso, "An Evaluation of the Treatment and Control Technology Recommended for the Blast Furnace (Iron) Wastewater," Mellon Institute, Carnegie-Mellon University, Pittsburgh, Penn., August 1976.

18. G. M. Wong-Chong, S. G. Caruso, and T. G. Patarlis, "An Evaluation of EPA Recommended Technology for the Treatment and Control of Wastewater from the By-Product Coke Plants--Alternate 2," Mellon Institute, Carnegie-Mellon University, Pittsburgh, Penn.

19. D. J. Juvan, "Design of Critical Water System for Continuous Casters," Tech. Paper No. 247, presented to 1975 AIME National Open Hearth and Basic Oxygen Steel Conference, Toronto, Canada, April 13-16, 1975.

20. H. F. Theegarten and R. K. von Hartman, "Hoesch Hüttenwerke's Hot Strip Mill Water Supply System," Iron and Steel Engineer, Vol. 50, No. 8, August 1973, p. 67.

21. P. Guyard, Tribune de Cebedeau, No. 255, 1965, pp. 58-74.

22. P. Mosel, Revue Technique Luxembourgeoise, No. 3, 1954, pp. 138-163.

23. N. Y. West, "Recycling Ferruginous Wastes: Practice and Trends," Iron and Steel International, Vol. 49, No. 3, June 1976, p. 173.

24. Curt Hazlett, "GM Probe May Solve Rust Riddle," American Metal Market/Metalworking News, Vol. 85, No. 234, Dec. 5, 1977, p. 12.

25. Y. Tamai and M. Sumitomo, "On the Nature of Oil-Burn on Steel Surfaces," J. Amer. Soc. Lubric. Eng., Vol. 31, No. 2, 1975, p. 81.

26. D. G. Miller and D. H. Newsome, "Conservation of Water by Reuse in the United Kingdom," Chemical Engineering Progress Symposium Series, Vol. 63, No. 78, 1967, p. 13.

27. Anon., Iron & Steel Engineer, Vol. 54, No. 7, July 1977, p. 63.

APPENDIX A

STATISTICAL HIGHLIGHTS OF THE U.S. IRON AND STEEL INDUSTRY[27]

		1976	1975	1974	1973	1972	1971	1970	1969	1968	1967
PRODUCTION (millions of net tons)	Total U.S. Pig Iron	86.9	79.9	95.9	100.8	88.9	81.3	91.4	95.0	88.8	87.0
	Total U.S. Raw Steel	128.0	116.6	145.7	150.8	133.2	120.4	131.5	141.3	131.5	127.2
	Open Hearth	23.5	22.1	35.5	39.8	34.9	35.6	48.0	60.9	65.8†	70.7†
	Basic Oxygen	79.9	71.8	81.6	83.3	74.6	63.9	63.3	60.2	48.8	41.4
	Electric	24.6	22.7	28.7	27.7	23.7	20.9	20.2	20.1	16.8	15.1
	Total Canadian Raw Steel	14.5	14.4	15.0	14.8	13.1	12.0	12.3	10.3	11.3	9.7
	Total World Raw Steel	753.1	712.0*	782.8	768.6*	694.5	639.9	654.2	632.0	582.5	547.6
SHIPMENTS (millions of net tons)	Total Steel Mill Products	89.4	80.0	109.5	111.4	91.8	87.0	90.8	93.9	91.9	83.9
	Carbon	80.3	70.8	98.0	100.9	83.2	79.3	83.2	85.1	83.2	76.0
	Alloy	8.1	8.4	10.2	9.4	7.8	7.0	6.9	7.9	7.8	7.0
	Stainless	1.0	.8	1.3	1.1	.8	.7	.7	.9	.8	.8
SHIPMENTS MAJOR PRODUCTS ALL GRADES (millions of net tons)	Shapes, Plates and Piling	11.3	13.9	18.1	16.8	13.2	13.6	14.1	14.5	14.6	14.1
	Bars and Tool Steel	14.2	13.4	18.5	18.2	15.5	14.2	14.6	14.4	13.7	13.1
	Pipe and Tubing	6.3	8.2	9.8	9.1	7.6	7.6	7.8	9.2	10.1	9.0
	Wire and Wire Products	2.5	2.2	3.2	3.2	3.0	2.8	3.0	3.3	3.4	3.1
	Tin Mill Products	6.4	5.7	7.5	7.3	6.1	6.8	7.2	6.6	7.3	6.6
	Sheets and Strip	42.3	30.8	45.0	49.4	39.9	35.6	35.1	38.1	36.6	32.6
SHIPMENTS MAJOR MARKETS (millions of net tons)	Automotive	21.4	15.2	18.9	23.2	18.2	17.5	14.5	18.3	19.3	16.5
	Steel Service Centers**	14.6	12.7	20.4	20.4	16.8	14.4	16.0	15.8	14.1	13.4
	Construction & Contractors' Products**	12.0	12.0	17.6	17.2	13.6	13.6	13.4	13.9	14.2	13.4
	Containers & Packaging	6.9	6.1	8.2	7.8	6.6	7.2	7.8	7.1	7.9	7.3
	Industrial & Electrical Machinery & Equipment	7.9	7.3	9.7	9.7	8.2	7.5	7.9	8.5	8.4	7.8
EMPLOYMENT	Average Number of Employees (thousands)	454	457	512	509	478	487	531	544	552	555
	Annual Wages and Salaries (billions)	$8.3	$7.4	$7.9	$6.8	$5.8	$5.2	$5.2	$5.3	$5.0	$4.7
	Total Employment Cost/Hr. Worked (hrly employees)	$11.74	$10.59	$9.08	$7.68	$7.08	$6.26	$5.68	$5.38	$5.03	$4.76
FINANCIAL	Net Assets (billions)	$27.5	$25.1	$22.8*	$21.2*	$20.5	$20.0	$19.7	$18.9	$18.5	$17.3
	Total Revenue (billions)	$36.5	$33.7	$38.2*	$28.9*	$22.6	$20.4	$19.3	$19.2	$18.7	$16.9
	Net Income (millions)	$1,329	$1,595*	$2,475*	$1,272	$775	$562	$531	$879	$992	$829
	Capital Expenditures (billions)	$3.3	$3.2	$2.1	$1.4	$1.2	$1.4	$1.7	$2.0	$2.3	$2.1
	Total Dividends Paid (millions)	$631	$658	$674*	$443	$402	$390	$487	$488	$451	$480
	Profit Per Dollar of Revenue	3.6¢	4.7¢	6.5¢*	4.4¢	3.4¢	2.8¢	2.8¢	4.6¢	5.3¢	4.9¢
	Percent Return on Stockholders' Equity‡	7.7%	9.8%	17.1%	9.3%	5.8%	4.3%	4.1%	7.0%	8.2%	6.9%
CAPITAL EXPEND'S FOR AIR & WATER QUALITY CONTROL	Capital Expenditures (millions)	$489.2	$453.1	$267.2	$100.1	$201.8	$161.6	$182.6	$138.0	$101.7	$94.1
	Water (millions)	$158.7	$131.8	$106.9	$34.7	$57.0	$73.4	$110.0	$71.0	$61.5	$54.7
	Air (millions)	$330.5	$321.3	$160.3	$65.4	$144.8	$88.2	$72.6	$67.0	$40.2	$39.4
FOREIGN TRADE (millions of net tons)	Imports, All Steel Mill Products	14.3	12.0	16.0	15.1	17.7	18.3	13.4	14.0	18.0	11.5
	Carbon	13.6	11.4	15.4	14.6	17.1	17.7	12.9	13.5	17.5	11.1
	Alloy	.483	.448	.413	.434	.448	.415	.349	.353	.316	.189
	Stainless	.175	.167	.176	.128	.149	.192	.177	.182	.172	.149
	Dollar Value (billions)	$4.0	$4.1	$5.1	$2.8	$2.8	$2.6	$2.0	$1.7	$2.0	$1.3
	Exports, All Steel Mill Products	2.7	3.0	5.8	4.1	2.9	2.8	7.1	5.2	2.2	1.7
	Dollar Value (millions)	$1,255	$1,862	$2,118	$1,004	$604	$576	$1,019	$796	$444	$415

* Revised figure.
† Includes any Bessemer production.
‡ As of January 1 of each year, rather than December 31, as in previous issues.
** Selected tonnage previously reported under this category now reported in oil and gas industry.